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AH-64 FLIGHT AND WEAPONS SIMULATOR CONCEPT FORMULATION STUDY.(U)

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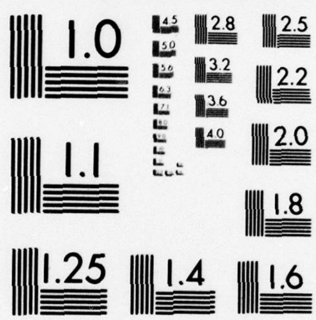

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AH-64

FLIGHT AND WEAPONS SIMULATOR

CONCEPT FORMULATION STUDY.

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PREFACE

This report presents the analysis, conclusions, and recommendations of the preparing activity, Sperry SECOR, regarding the optimum design of a flight and weapons simulator for the AH-64, the Advanced Attack Helicopter.

The report details the results of a study conducted for the Naval Training Equipment Center, Orlando, Fla., under Contract Number N61339-77-C-0048, dated 14 February 1977.

Sperry SECOR wishes to acknowledge the assistance provided by the many military and contractor personnel who generously gave their time in interviews and discussions, and often provided extensive reference material. Of particular note was the assistance provided by PM TRADE, the U.S. Army Aviation Center, and the U.S. Army Armor Center.

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INTRODUCTION AND SUMMARY

PURPOSE OF THE STUDY

The purpose of this study is to determine the optimum design features of an Advanced Attack Helicopter Trainer. The study has been prepared for the Naval Training Equipment Center, Orlando, Florida, in accordance with the specification entitled "AH-63/64 Flight and Weapons Simulator Concept Formulation Study," dated 12 July 1976, as amended by the Computer Section Study Outline appended to the contract. Since publication of the specification, the Hughes AH-64 has been selected to be the Advanced Attack Helicopter; and the terms Advanced Attack Helicopter Trainer (AAHT) and AH-64 Flight and Weapons Simulator (FWS) are used synonymously in the study.

METHODOLOGY

The study was conducted by a project group composed of analysts, engineers, and training specialists, each individual having qualifications in one or more of the various areas of investigation. Under direction by the Director of Engineering, Sperry SECOR, the group consisted of several members of Sperry SECOR, Fairfax, Virginia; a member from Sperry System Management, Great Neck, New York; and, as a consultant, a member from Seville Research Corporation, Pensacola, Florida. Each member contributed directly to the study, by writing sections related to his area of expertise.

The study was prepared in three phases: a data-gathering phase, an approach-definition phase, and a report-writing phase. As predicted in the Sperry SECOR proposal, the phases tended to overlap each other.

Data was obtained by a number of methods. Initially, discussions were held with persons directly interested in the

study, at PM TRADE, Naval Training Equipment Center, Orlando, Florida; the Armor Center, Ft. Knox, Kentucky; and the Army Aviation Center, Ft. Rucker, Alabama. Later, those contacts were broadened to include interviews with training supervisors, helicopter pilots, and simulator instructors. Helicopter flights were made at Ft. Rucker, Alabama and Ft. Bragg, North Carolina, to observe techniques of nap-of-the-earth flying, acquisition and identification of typical targets and other aspects of attack helicopter training. For the latest data on the Hellfire missile system, program managers and engineers were interviewed at the Hellfire Project Manager office, Redstone Arsenal, Alabama; and at Rockwell International, Columbus, Ohio. Visits were also made to the U.S. Army Night Vision Laboratory, Alexandria, Va. and the Air Force Human Resources Laboratory at Williams AFB, Arizona. To obtain information on visual system technology, visits were made to Singer Link Division, Sunnyvale, California; and Evans and Sutherland, Salt Lake City, Utah. Perhaps the most important source of information was the large volume of reports and specifications generously provided by PM TRADE.

Visits, interviews, and helicopter flights were performed by a limited number of study group members. Their observations and all published data were made available to all members as required.

SUMMARY ANALYSIS OF TRAINING REQUIREMENTS

The mission of the Advanced Attack Helicopter, the AH-64, will be to perform air cavalry and aerial escort roles, and to conduct direct aerial fire against enemy armor and other mechanized targets. Generally speaking, the role of the AH-64 will be similar to that of the Cobra, the AH-1. Manned by a crew of two - a pilot and a copilot/gunner, the AH-64 will be armed with Hellfire laser-guided missiles, 2.75-inch rockets, and a 30-mm gun. Visionic equipment will consist of the Target Acquisition

and Designation System (TADS), the Pilot Night Vision System (PNVS), and the Integrated Helmet and Display Sight System (IHADSS). In general, the copilot/gunner, who occupies the front seat, will perform navigation and operate the weapon systems, and the pilot, in the rear seat, will fly the helicopter, although all weapons and most visionic equipment can be operated from either position.

The AAH will conduct tactical operations in day or night, and will be capable of IFR navigation. Normally, the helicopter will approach target areas by terrain flight tactics (contour, low level, and NOE); and will engage targets either autonomously or by using designator aircraft or ground personnel. If a hostile ground or air threat is encountered, the AAH will take appropriate evasive or defensive action.

Deliveries of the AH-64 to U.S. Army field units are expected to commence in the 1980-1982 period. The AH-64 FWS should be available in the same period.

A simulator (or simulator system) to conduct pilot and gunner training for the AH-64 will be required to have a broad range of capabilities. The following requirements are basic:

Realistic depiction of the scenes that the pilot and gunner will see during terrain flight navigation.

Depiction of targets, with sufficient resolution to permit identification and acquisition, at ranges appropriate to the AH-64 weapons.

Simulation of the AH-64 visionic equipment.

Simulation of all modes of fire of the missile, rocket, and gun systems.

Simulation of the flight characteristics of the AH-64 helicopter.

Simulation of instruments and controls at the pilot and gunner positions.

Simulation of intercom and radio systems, including their use in air traffic and tactical modes.

Simulation of threats to the airborne AH-64.

In addition, the simulator will be required to enable an instructor to initiate and control training exercises, and observe and evaluate student performance.

These requirements can also be viewed functionally. Training in the AH-64 can be categorized as either "institutional" or "operational." Institutional training is that familiarization and initial qualification instruction given at Ft. Rucker, Alabama; and operational training would be the more advanced, continuation training conducted at units located worldwide. The AH-64 FWS must be capable of meeting both types of training requirements.

Institutional training (in the AH-64 FWS) would include:

Aircraft handling
Normal and emergency procedures
Instrument flight and navigation
Terrain flight and navigation
Weapon indoctrination

Operational training would consist of:

Maintenance of proficiency in emergency procedures, instrument flight and terrain navigation
Maintenance of proficiency in operating all weapons and visionic systems (by both crewmen)
Crew coordination, in connection with NOE navigation, target acquisition, and weapon delivery.
Tactical decision-making
Simultaneous engagement of multiple targets
Response to hostile actions (small arms, radar, AAA, enemy aircraft)
Coordination with scout helicopters, ground personnel, forward air controllers, etc.

CONCLUSIONS AND RECOMMENDATIONS

In consideration of the training requirements summarized above, the Sperry SECOR study group visualizes the AH-64 FWS primarily as a full-mission trainer capable of providing a broad range of both institutional and operational training, and enabling integrated pilot and copilot/gunner training in those areas where crew coordination is important.

The cockpit would replicate the tandem seating of the AH-64 and would be mounted on a 6-degree-of-freedom motion base with reduced excursions (see Figure 1). Proposed is a visual system using computer-generated imagery (CGI) projected on a wide-angle (180-degree), fixed-base, cylindrical screen by five Hughes liquid crystal light valve projectors.

The instructor station, which would be situated remote from the cockpit, would be normally manned by one instructor, or two on occasions when simultaneous training demands on the pilot and copilot/gunner require, and would accommodate a number of observers if desired.

The instructor station would contain two 21-inch CRT's for problem control and student monitoring, two 5-inch CRT's for monitoring the pilot and copilot-gunner's visionic displays, and five 5-inch CRT's that would reproduce the visual system displays.

A variety of displays and instructional programs would enable the instructor to enter malfunctions by several methods and to monitor the student's procedures; to play back a student's maneuvers in order to show him his mistakes; to show demonstrations of correctly performed maneuvers; to evaluate student precision-flying ability on both instrument and visual flight profiles; to evaluate student proficiency in weapon delivery; and to print out CRT displays for critique purposes. Graphic displays would enable the instructor to monitor training in

instrument navigation and approaches. Included would be a combat situation display by which the instructor could control targets, threats, and friendly elements that would be depicted on the visual display and require decisions and responses by both the pilot and copilot gunner.

The study group recognizes the limitations of a CGI display system (as well as a terrain model board) with respect to NOE navigation and target detection and identification, and recommends that a part-task trainer be included in the AAH simulator system to accomplish training in these areas. This trainer would represent the gunner's cockpit and would use a wide-angle (60-degree) cinematic system with either a flat or curved screen to produce the visual display, and a vibration system to provide disturbance motion cues. The instructor station would be located immediately to the right rear of the student. Films of NOE flight routes would enable the student to correlate map symbols with observed scenes and thus practice navigation, and films of armored vehicles and other targets in various degrees of concealment would enable training in target detection and identification. Controls for the visionic equipment would permit the student to receive training in operating procedures.

Thus, the study group recommends that the AAH simulator system consist of two trainers, one possessing a full-mission training capability within the limitations of current interactive visual systems, and the other providing part-task training where a high degree of visual resolution and realism are necessary. These two trainers would be designated the AAH Mission Trainer (MT) and the AAH Navigation and System Procedure Trainer (NSPT).

The study group has considered the possibility of performing both the MT and NSPT functions with a single trainer, by installing the cinematic visual system on the Mission Trainer and

using a portion of the same screen. Coordinated CGI and cinematic scenes would not be attempted. The main argument against this concept is that the part-task training would reduce the time available for mission training, but the savings in equipment and facilities appear to outweigh the disadvantage. Sperry SECOR recommends that an analysis of AH-64 trainer expected availability versus utilization be made to determine whether the concept of a combined MT and NSPT is acceptable.

The study group has arrived at many peripheral conclusions regarding the components of the simulator; supporting areas, including logistical; aerodynamic and engine simulation; and instructional systems. These conclusions and corresponding recommendations are contained in the various sections, following, in this report.

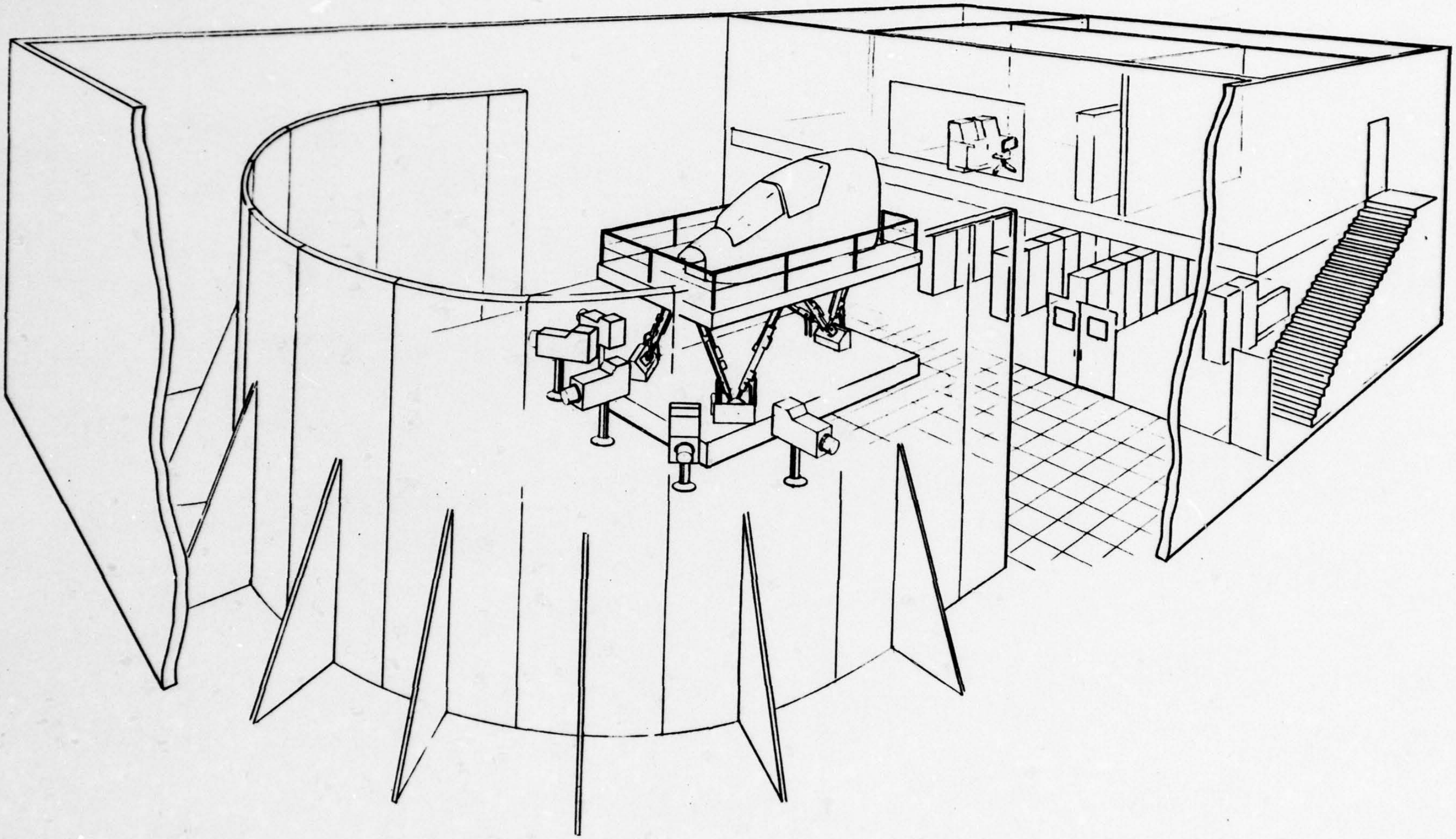

Figure 1. Artist's Concept of the AH-64 FWS Mission Trainer

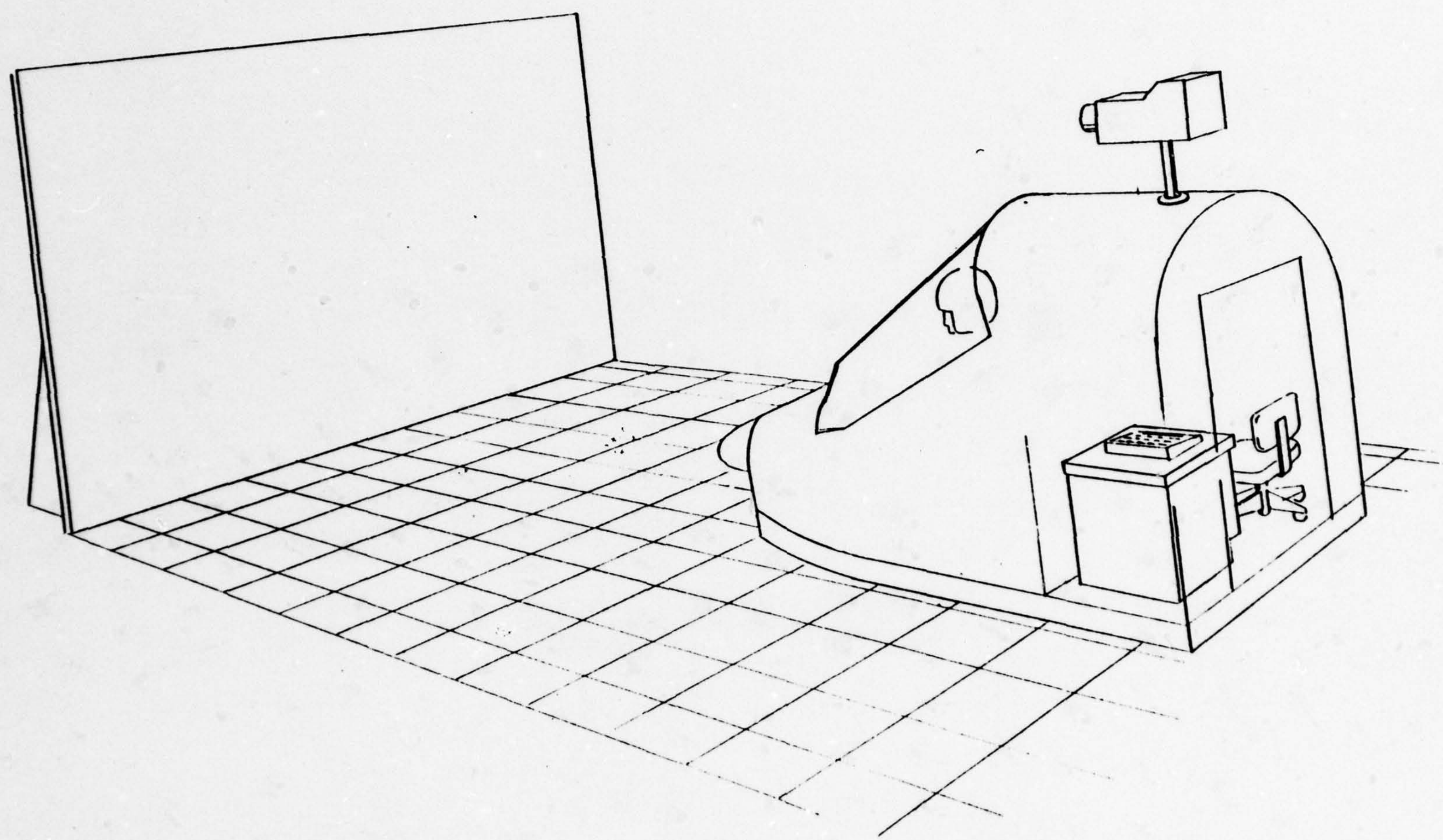

Figure 1a. Artist's Concept of the AH-64 FWS Navigation and Systems Procedure Trainer

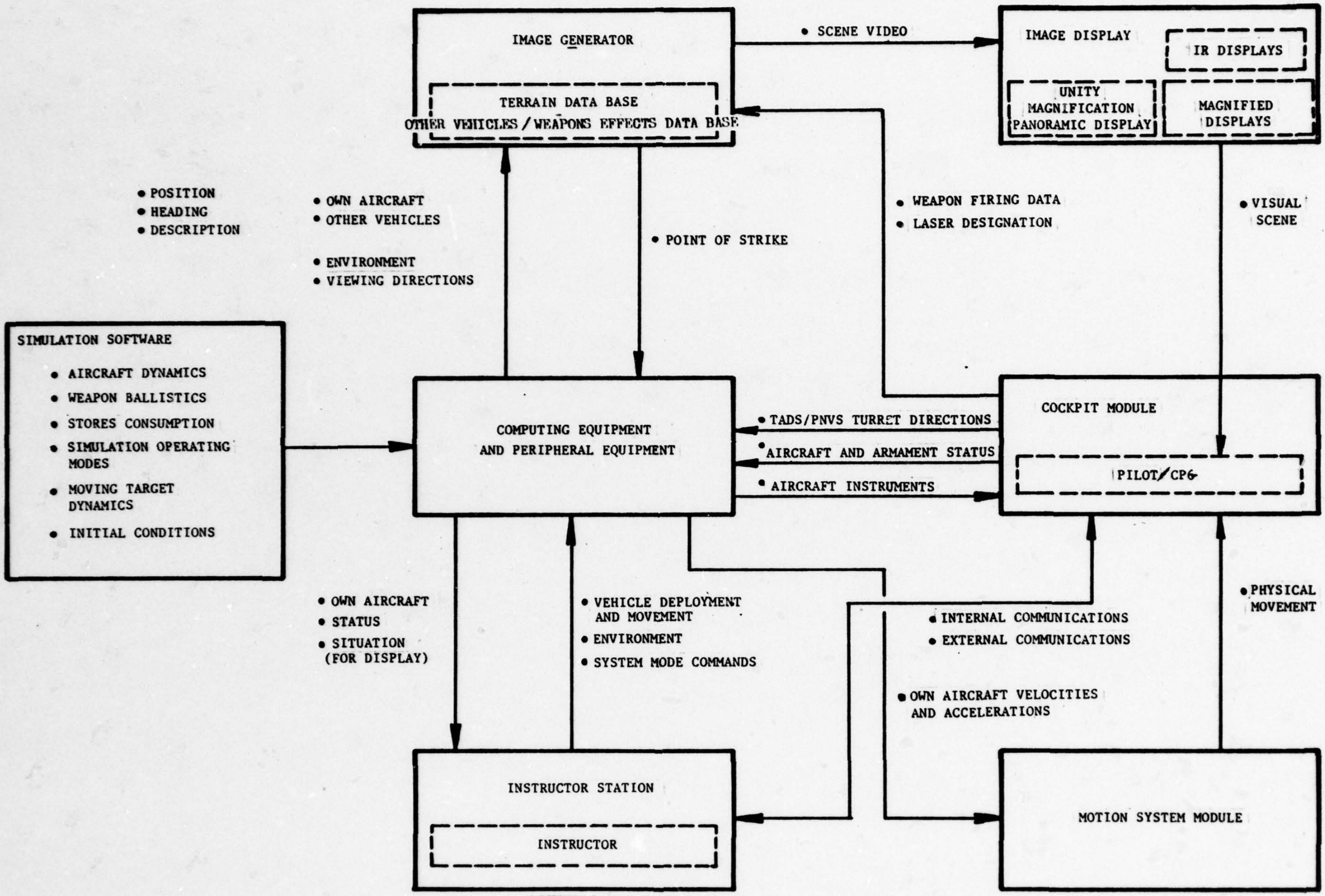

Figure 2. AH-64 Mission Trainer

SECTION II

ANALYSIS OF AAH TRAINING REQUIREMENTS

As a part of the AH-64 Flight and Weapons Simulator Concept Formulation Study undertaken by Sperry-SECOR, a review was conducted of the performance requirements associated with the AAH pilot and gunner as those requirements are understood at the present time. The review included extensive interviews with Army aviators who expect to participate in future AAH training activities, aviators who have flown a wide variety of missions in Army aircraft (with an emphasis upon those who have had operational experience with the AH-1 Cobra), and aviators who participated in the operational testing of the AAH itself. In addition, pertinent Army aviation training programs were reviewed, design documents describing the AAH and its various on-board systems were analyzed to identify operator requirements and reports of earlier studies in which Army aircrew task analyses have been conducted and training objectives derived were studied. From these efforts an understanding of the roles of the AAH pilot and gunner has evolved, and, from that understanding, training requirements have been organized in a manner that can be related to AAH simulator design and training concepts. The present section of this report describes those relationships so that the reader will have a better appreciation for some of the concepts embodied in the simulator design described elsewhere.

AAH PILOT/GUNNER TRAINING REQUIREMENTS

The AAH is being developed by the Army to perform a mission similar to that currently being performed by the AH-1 Cobra. While the AAH may replace the AH-1 at some indefinite future time, due to attrition or other factors, current plans are that the two vehicles will perform, together, virtually the same operational mission. There are some differences in the

battlefield performance capabilities of these vehicles, and the survivability of the AAH is expected to be greater. From the pilot and gunner training standpoint, however, the requirements associated with the AAH are expected to parallel in all significant respects the requirements associated with the AH-1. These requirements are discussed below.

Pilot Training Requirements

The pilot will be responsible for the overall conduct of the AAH mission. Although he may elect under some circumstances to assign certain tasks he normally performs to his gunner, e.g., mission planning and conducting radio communications, he will retain responsibility for their performance, so such tasks are viewed here as pilot tasks rather than gunner tasks. Likewise, there are tasks that can be performed in the AAH by either the pilot or the gunner by virtue of the fact that duplicate displays/controls are located at each position. These tasks also are viewed here as pilot training tasks. It should be noted that it is firm Army policy that all AAH gunners will be fully qualified AAH pilots.

Mission and Flight Planning. Tasks associated with AAH mission and flight planning include reviewing the tactical situation and the capabilities of the enemy threat, planning flight routes and attack positions, obtaining maps, utilizing appropriate aircraft and air traffic control reference sources, and filing the appropriate flight planning documents. Verifying the readiness for flight and for the mission of the assigned aircraft are also tasks that can be considered to be within this category. The training related to the AAH required for the pilot with respect to these tasks consists of those activities involving preflight

of the aircraft itself and assuring that its stores/fuel loadings are within required operational limits. Preflighting tasks involving portions of the aircraft external to the simulated cockpit areas are not of concern to a simulator training requirement, of course. Other mission and flight planning tasks can also be a part of a training activity involving an AAH simulator, but they constitute training program design considerations, i.e., how the simulator is used, rather than simulator design considerations. Therefore mission and flight planning tasks have no significant implications for AAH simulator design.

Aircraft Operation and Control. Tasks associated with AAH operation and control consist of performance of all cockpit checklist items and tasks that involve aircraft handling, i.e., controlling the position, attitude, and movement of the AAH with respect to external objectives and features of the environment. Examples of aircraft handling tasks include taxi, hover, takeoff, enroute flight, approach to an operational or landing area, and landing. All basic aircraft maneuvers are included in these tasks, and skill at them is prerequisite to performance of operational missions in the AAH. However, skill at the performance of aircraft operation and control tasks does not assure that the pilot will be able to perform an operational mission or any tactical element of such a mission. The performance of mission related tasks is discussed in subsequent sections.

The most common use of modern aircraft simulators is in the conduct of pilot training related to aircraft operation and control tasks, and it should be planned that the AAH simulator will be the primary locus of such training for the AAH pilot. The basic simulator design implications of the

requirements for such training are for a device that closely resembles in appearance and size the interior of the cockpit (pilot position) of the AAH with controls and displays that correspond in function to the same items in the aircraft's cockpit. All on-board systems with which the pilot interacts must also be simulated with respect to both normal and abnormal or emergency conditions. Additional requirements relate to simulation of the atmospheric and electronic environment in which the simulated aircraft operates, and simulation of motion, visual and sound cues essential to the tasks being performed. A more comprehensive and precise specification of the features and characteristics of an AAH simulator is presented elsewhere.

Instrument Flight Missions. The instrument flying tasks associated with AAH training are virtually identical to those associated with instrument flying in other instrument-equipped Army aircraft, except to the extent that the cockpit displays themselves may differ among aircraft. Instrument flight training has historically been a primary function of aircraft simulators, and the technology with respect to both simulator design and training program design needed to support such training is readily available. A simulator in which AAH operation and control tasks can be performed and that contains simulation of the instrument navigation environment would be suitable for conduct of AAH instrument training. Virtually all (i.e., 95%+) AAH instrument training can be provided in such a device.

Terrain Flight Missions. Terrain flight consists of flying at speeds varying from 0 to 80 knots at altitudes varying from below treetops and other masking features of the terrain to an altitude high enough to clear the highest obstacle in the flight path. The tasks involved in terrain

flight include hovering in and out of ground effect; contour, low-level and NOE flight; all aircraft operation and control flight tasks; masking and unmasking; performing quick-stop maneuvers without unmasking; determining obstacle clearances; and performing evasive maneuvers. Terrain flight requires a high degree of skill on the part of the pilot because of the constant danger of blade strikes and collisions with objects and with the terrain itself. Terrain flight operations occur within a very restricted and cluttered airspace, and as a consequence, a much higher aircraft control skill level is required than for operations in more open airspaces.

It should be noted, however, that it is not necessary to develop all of the necessary aircraft control skills in such a threatening environment. A high degree of skill in maintaining precise control over the position and movement of the AAH can be developed in another more open environment and transferred to the cluttered terrain flight environment, thus reducing the magnitude of the terrain flight training requirement. For example, a pilot who learns to fly "on instruments" to a high skill level, particularly if the instrument displays permit him to maintain very close tolerances on all attitude, position and rate parameters, likely will develop terrain flight aircraft control skills much more rapidly than will a pilot trained to less precise instrument flight standards.

Because of the potential dangers of conducting flight training in the terrain flight environment, the AAH simulator is a highly desirable locus for such training. The extent to which terrain flight mission training activities can be accomplished in a high fidelity simulator such as would be required for conduct of the other simulator training discussed above will be limited by the device's visual display and motion system.

Visual display and motion system requirements related to terrain flight mission training are discussed below.

Terrain Flight Navigation. Navigation consists of maintaining continuous, accurate geographic orientation. Gainer and Sullivan (1976a, 1976b) have pointed out that the navigation skills required at high altitude in a benign environment are virtually irrelevant in a terrain flight environment. Instead, the pilot must acquire skills involving accurate terrain analysis, precise piloting in a highly restricted visual field, and valid and rapid map interpretation. Even for the highly skilled and experienced Army aviator, terrain flight navigation is extremely difficult, particularly when operating in relatively unfamiliar terrain.

Factors which must be considered in the specification of training requirements for terrain flight navigation include a greatly restricted geographic area of view, terrain and vegetation masking, a sharply oblique view of the terrain, a highly dynamic visual scene, a high angular velocity of objects in the visual field, and a distorted relationship between visually observed features of the environment with respect to their representations on maps. In addition to these factors, the pilot engaged in the terrain navigation task must simultaneously perform a variety of aircraft control tasks, monitor the cockpit displays, make tactical decisions, and manage the weapons and avionics systems (he may assign some of these tasks to the gunner). The requirement under most terrain flight mission conditions to make frequent changes in airspeed makes dead-reckoning navigation techniques useless, and there are virtually no navigation aids reliably available.

Terrain navigation training is a formidable task for the AAH pilot. Because of safety restrictions as well as resource limitations, the conduct

of this training in the AAH itself must be restricted. This is an important area where a simulator may be employed. Because of the severe visual cue requirements associated with terrain navigation and the need to correlate observed features with their cartographic counterparts, however, present state-of-the-art simulators do not provide the full-mission terrain navigation training potential that may be desired. Simulator visual display considerations related to terrain flight navigation are discussed elsewhere. While simulators will undoubtedly prove indispensible in AAH terrain navigation training, it is likely that the AAH itself will also play a significant role in that training.

Target Detection and Identification. Target detection and identification in the AAH is a task that is primarily performed visually by the pilot. He frequently will be aided by having a particular target called to his attention by the gunner, by the crew of another aircraft, or by a ground observer. The task involves skills such as analysis of the terrain and the tactics and capabilities of the threat in order to identify potential target locations, approaches, and types; detection of target signatures such as sun reflection, movement, dust trails, and weapons flash; and recognition of familiar target shapes, patterns and colors. While, in the past, aircraft have sometimes been used as platforms from which target detection and identification training have been conducted, the more successful training related to these tasks has been conducted in non-flight environments such as classrooms. Simulation offers some potential for the conduct of such training, since many of the successful classroom training techniques probably can be adapted to the simulator environment. Target detection and identification training and the associated AAH simulator visual display requirements are discussed elsewhere.

Target Engagement. The target engagement task for the pilot consists of four principal elements: (1) maneuvering the aircraft into and maintaining (as required) an attack or weapons release envelope; (2) weapons selection/preparation; (3) weapons release; and damage assessment. The first element is basically that of controlling the aircraft and has been discussed above. An added component of the task involves time sharing aircraft control with cognitive activities associated with threat analysis, evaluating tactical alternatives, and planning the attack. The second element involves the execution of procedural tasks and checklists, and it too must be time shared with cognitive activities as well as with aircraft control. Weapons release for the pilot, assuming the two earlier task elements have been performed correctly, is a relatively simple task for some weapons, e.g., rockets, and involves only maintaining the aircraft in a steady, in-trim state for a relatively brief time interval. For weapons such as the mini-gun or cannon, the pilot must respond to visual cues derived from weapons tracers or impact to adjust his aim as may be required. The pilot normally will not fire the AAH's flexible aim weapons or the missile, and his only task associated with their use by the gunner involves positioning the aircraft and remaining within a prescribed envelope until the gunner's task is completed. For damage assessment, the pilot may be aided by the gunner who will employ the optical sighting device available to him to obtain a magnified view of the target.

Use of the AAH simulator for target engagement training of the pilot is highly desirable due to the high cost of such training in the aircraft. Except to the extent that visual display technology imposes limits upon the visual detectability of appropriate targets, the AAH simulator will provide an excellent vehicle for most target engagement training activities.

Because of visual display limitations, however, it is likely that the aircraft will continue to be necessary for a portion of such training and to provide confirmation of the effectiveness of training conducted in the device. Visual display considerations related to the use of simulators for target engagement training are discussed elsewhere.

Night Missions. It is projected that the AAH may be required to engage in a significant amount of night, restricted visibility, or low light level operations. These operations will potentially include the full range of day operations discussed herein, each of which will be made more difficult to perform by virtue of the poor visibility associated with night operations. In the tactical environment, security requirements will dictate that there be little or no cultural lighting to provide navigation and orientation cues at night, and the illumination from fire, flares, and weapons flashes will be of only limited help because of the necessity to fly at NOE altitudes where they may be visible only infrequently. To avoid detection and to maintain dark adaptation, the AAH's landing and search lighting equipment will seldom be used except in the secured stagefield environment.

Operation of the AAH under night and dusk conditions in a tactical environment without electronic viewing aids will be a formidable task for which training can provide only limited relief. The best preparation for such a requirement will be to develop high levels of skills at the tasks required for operation under daylight levels of illumination so that less attention will be required for their performance at night and more attention can be directed to seeing hard-to-distinguish objectives and features of the environment. Such high skill levels can be developed in a simulator

without a night simulation capability, although a "night visual" simulator might be useful to train pilots to recognize specific light patterns.

Operation of the night viewing aids available to the AAH pilot will require training. While use of light enhancement goggles is not a demanding task per se, the pilot will be required to practice using them, primarily to adapt to the reduced field of view they permit. The infra-red and LLLTV displays, when viewed through the pilot's helmet visor, will present training problems associated with display interpretation, i.e., recognition of objects and features of the environment under various conditions of illumination and heat retention. The technology is available to provide such training in an AAH simulator, although it is likely that a portion of the flight training will continue to be conducted in the AAH in order to build pilot confidence as well as to assure the validity of the overall training program.

<u>Communication and Coordination</u>. The AAH pilot does not operate alone. He must function as an integral part of the crew of the aircraft and, often, of an attack unit involving other aircraft and ground elements. Primarily, the pilot must employ his radio and intercom system to effect the necessary communication and coordination, but to a lesser extent, he may employ visual cues such as hand signals, smoke, flares, and the maneuvering of his own or other aircraft. Provision of the appropriate communication capability in a AAH simulator is straightforward and requires no design features not required to support almost any other training likely to be conducted in it. Provision of the desired visual cues in dynamic (i.e., not canned, pre-programmed) fashion, however, is a formidable task and may not be fully achievable with present-day technology. For

this latter reason, the communication and coordination training requirement associated with the AAH and its missions received particular attention during the present study.

With respect to communication and coordination between the pilot and the gunner in his own ship, personnel experienced with the AH-1 Cobra and the AAH equate the two so far as these task requirements are concerned. Primary coordination in the Cobra takes place via intercom during all mission activities from the time power is applied prior to flight until the aircraft is shut down at the conclusion of a mission. A secondary but important means of communication and coordination involves the use by the pilot of his helmet sight to point out targets to the gunner by slaving the gunner's TADS and optical sighting devices to it. This technique, which is available in the pilot-to-gunner direction only, has virtually no training requirement associated with it. In addition, the gunner, on rare occasions, may employ hand signals to communicate with the pilot, but, because of the configuration of the vehicle, this channel cannot easily be reversed. Here again, however, hand signals are employed to indicate direction only, and training needs associated with them are minimal.

Communication and coordination with elements outside the AAH present somewhat more of a training problem. To the extent that that problem can be met through use of the aircraft's communications equipment, training in a simulator is likely to be as effective as training in the AAH itself and can be conducted more efficiently. To the extent that visual contact must be maintained with other attack units, whether on the ground or in the air, the probable value of simulator training is more limited. Both visual communication and coordination of attack activities require closed-loop interaction between participating elements. While the construction of a

simulator that would involve multiple unit interaction is technically possible, its cost would likely far exceed its value for training. In that regard it should be noted that AH-1 pilots who were questioned concerning the manner in which they communicated non-verbally with other attack elements and the effectiveness of that communication reported consistently that they experienced no problem in achieving effective coordination. While these reports can be questioned, they do suggest that the techniques involved either were adequately supplemented by available verbal communication channels or that the techniques required were available without specific training.

Comments by Gainer and Sullivan (1976a) concerning verbal communication requirements during NOE flight are generally applicable to all missions that will involve the AAH. These researchers point out that effective communication involves formulation and transmission of relevant, accurate, and intelligent messages as well as the ability to understand and follow specified communication procedures. They suggest that simulators provide an efficient medium for the development and maintenance of the procedural skills involved in effective communication. Training related to cognitive functions, such as decision making, verbalization, enunciation, vigilance, audition, attention sharing, memory and judgement, present more of a challenge. Developing these latter skills in an AAH simulator will require imaginative planning to provide a meaningful and stressful situational context that will permit training to deal with such problems as failure to communicate timely messages, untimely communications, garbled syntax, unintelligible speech, misunderstandings and misattributions.

Reconnaissance, Indirect Fire Control, and Intelligence. The AAH pilot must be trained to perform a wide variety of higher order activities involving use of his aircraft as an aerial vehicle. Many of these activities require that he be intelligent, innovative, adaptable to the environment and the threat at hand, and responsive to a highly dynamic situation. These activities are dependent upon the prior development of skills previously discussed. For example, the effective conduct of a reconnaissance or fire control mission requires that the pilot be able to control his aircraft, navigate effectively, and maintain precise geographic orientation. Once these underlying skills are developed, many of the required higher order skills can be developed with relative ease, and special training in the aircraft or a simulator may not be required. Other higher order activities, such as those associated with intelligence (e.g., deceiving the enemy as to his unit's tactics and collecting information of potential intelligence value), while also dependent upon the same underlying skills, are not so easily developed.

The extent to which useful higher order skills such as those discussed above can be trained in a simulator--or, for that matter, the extent to which they can be trained in the AAH itself--is not known at the present time. Important though they are, activities employing some of these skills have not been subjected to the kinds of job analysis that would permit their precise definition. While it is likely that a simulator could be designed that would provide practice at tasks involving reporting what is seen along a flight route, estimating distances and directions of simulated weapons impact to targets, and employing circuitous flight routes, the value of such training in a simulator with limited cue possibilities would be

questionable. Training objectives involving such higher order skills specified in the obsence of an adequate job analysis are viewed as possible "high risk" objectives so far as AAH simulator training is concerned.

Tactics Training

The ultimate goal of any aircrew training is effective employment of a weapon system in combat. Thus, tactics training for the AAH aviator involves training encompassing each of the areas discussed above. In addition the pilot must exhibit sound judgement, effective decision making, ingenuity and a host of other high-order skills. Since these skills are difficult to define, it is even more difficult to define training requirements and simulator features appropriate to their development.

It is possible, however, to cite examples of aviator behaviors that illustrate some of these higher order skills and to design simulator and training programs around them. In the case of the AAH, for example, behavior can be identified that will increase battlefield survivability and therefore make effective weapons system employment more likely. Such behaviors include limiting exposure to possible anti-aircraft fire by avoiding flying through clearings, down highways and rivers, and along ridge lines; effective use of the terrain for concealment; altering attack routes and positions; and employing a variety of types of evasive maneuvers when under fire. Relatively simple algorithms can be devised that will permit an AAH simulator to be used effectively for such training.

Tactics training that involves dynamic interaction with an enemy force in a realistically simulated tactical environment presents more difficult training and simulator design problems. A principle character-

istic of the battlefield is the use of the terrain and its cultural and natural cover for concealment. Designing a simulator in which visual presentations are appropriate to the training of aviators to interact with an enemy in such a visual environment, while possible with current simulation technology, is hampered by the absence of tactical doctrine and relevant training objectives. Currently available task analysis methodologies are inadequate to the determination of these objectives. Therefore, the best that the simulation designer can do at the present time is to point out the need for better definitions of the relevant tactics and related training requirements and to design simulators that can be adapted to those requirements when they are developed.

Gunner Training Requirements

In the case of the AH-1 Cobra, the bulk of the aircraft qualification training takes place while the trainee occupies the aircraft's pilot position. The trainee receives training in the gunner position approximately 10% of the time. This ratio accurately reflects the facts that (1) most AH-1 aircrew tasks can be performed and learned from the pilot position; (2) transfer of training from the pilot position to the gunner position is virtually 100% for all tasks that can be performed from both positions; and (3) the few tasks that can be performed only from the gunner position are relatively simple and easy to master by anyone who has previously mastered the aircraft pilot's tasks. Front seat training in the AH-1 concentrates primarily upon operation of the target acquisition and weapon systems that must be operated from that position.

The tasks of the gunner in the AAH are comparable in most respects to the tasks of the gunner in the AH-1, and the training considerations

applicable to one of these aircraft are also applicable to the other. Personnel who are familiar with both vehicles indicate that the virtual identity of aircraft controls and associated displays between the two AAH crew positions (as contrasted with dissimilar controls in the AH-1) will facilitate the transfer of aircraft operation and control skills from the pilot to the gunner position even beyond that between comparable positions in the AH-1. In fact, it appears likely that tasks which can be performed from either cockpit (e.g., aircraft operation and control, navigation, and reconnaissance) need be trained only in one of the two crew positions. In the present discussion, preference is given to the conduct of such training in the pilot position, although the alternate options would be equally viable in most cases.

During unit training exercises not involving an instructor pilot, the gunner practices tasks associated with mission accomplishment from the front seat, of course, This training undoubtedly is helpful in increasing/maintaining gunner skills, although there are few tasks that are practiced during the flight that are not being practiced equally effectively by the pilot in the rear seat. Except to the extent that these flights provide an opportunity for the gunner to increase/maintain his skills in the relatively simple tasks unique to the front position in the AAH, the chief advantage they provide is the opportunity to practice, along with the pilot, higher order tasks such as navigation, target identification, night missions, communications, etc.

There are important tasks that are primarily or exclusively gunner tasks and for which training must be provided while the trainee occupies the front cockpit position. These tasks are discussed below.

Aircraft System Operation. There are tasks involving operation of aircraft systems that can be performed only from the gunner position. Execution of aircraft start-up and other checklists requires completion of certain steps by the gunner in coordination with the pilot, and these procedural tasks must be learned. In addition, there are weapons selection, target designation, and electronic countermeasures panels that must be operated by the gunner during certain missions because they are not available to the pilot. These gunner tasks are primarily procedural in nature and can be trained in a simulator.

Target Acquisition and Designation. The gunner in the AAH has primary responsibility for acquiring targets through viewing aids located in the front cockpit. These aids provide both image enhancement through infrared and TV sensors and magnification through optical viewing devices. They are very well engineered from the standpoint of operator tasks, and the development of skills in their use is neither difficult nor time consuming. The design of the equipment virtually eliminates the need to develop complex psychomotor tracking skills, and there are no significant requirements for cognitive skills associated with their use. Except for procedural tasks involving a relatively small number of steps, the training requirements per se are almost nil. Designating a target, i.e., illuminating it with a laser, is associated with these sighting aids and requires no additional psychomotor skills than operating the aids alone. Procedural steps associated with target designation also are few and do not involve complex contingencies. Cognitive learning demands upon the gunner are limited essentially to considerations related to safe use of the laser. In fact, once the procedural skills are acquired, successful operation of these

systems in the operational environment without further training is a high probability event. It is likely that the necessary skills would be acquired in most instances during the course of routine, non-tactical operation of the aircraft in support of other necessary flying. While much of this training could be conducted in a simulator, a simulator is not viewed as necessary to such training, nor is it likely to reduce use of the aircraft since flights necessary for non-individual training purposes can also be used to provide the desired training opportunities. Because of the potential injuries to personnel and livestock that could be inflicted through unrestricted use of the laser designator, however, such training would require detailed planning if it were to be conducted exclusively in aircraft.

Target Engagement. The target engagement task of the AAH gunner will involve firing the flexible weapons and the missiles. Firing the flexible weapons is a task that requires practice to develop psychomotor skills in order to maintain fire on a target. Since the gunner is not required to pilot the aircraft while engaging in the target engagement task, he has a relatively light time-sharing requirement while firing, and simultaneous cognitive demands also are minimal. To the extent that the targets of interest can be represented on its visual display, the simulator is an appropriate locus for the development of the skills underlying employment by the gunner of the AAH flexible weapons.

Firing the missile, when that task is separated from the target designation task (which may or may not be performed by the gunner in any specific instance), is essentially a procedural task involving final preparation of the missile through discrete controls on a gunner cockpit panel, verifying that the orientation of the aircraft is within the required launch envelope,

and missile release. If the gunner is also designating the target, he must time share that task with missile firing, but both these tasks are sufficiently well engineered that the acquisition of acceptable levels of skill and the maintenance of proficiency will not require great amounts of training in a simulator or in an aircraft. The major portion of the procedures associated with missile preparation will be performed on the ground prior to takeoff, normally will not be subject to critical time pressures, will not have to be time shared with other tasks, and will make few cognitive demands on the gunner. It is believed that a simulator with an appropriately designed visual display will be an acceptable medium for the bulk of the training that will be required. The visual display requirements for the gunner that are related to target engagement are discussed below.

Night Missions. In addition to the night mission skills that the gunner will acquire during his training as an AAH pilot, he will be required to learn to operate the infrared equipment from the controls located at the gunner position. The task will involve operating the panel controls to obtain useable images on the display scope or on his visor and the interpretation of the images obtained. This training can be provided in a simulator, or even in a part task trainer, in which a range of displayed images could be provided so that the gunner can practice adjusting the sensitivity of the equipment and interpreting the IR signatures of the objects involved.

Communications and Coordination. Although skills necessary to tasks associated with communications and coordination will be developed by the gunner largely during his training as an AAH pilot, the requirements for

his coordinated participation in all AAH operational missions is such that additional comment is appropriate here. During a tactical mission, particularly in the terrain flight environment, the gunner will perform most of the visual navigation tasks, leaving the pilot relatively free to attend to aircraft control and obstacle avoidance. Most of the controls associated with employment of the missiles and with use of the IR and TV sensors are located in the front cockpit, so extensive verbal communication is required between crew members where use of this equipment by the pilot is concerned. The gunner and pilot share the tasks of observation, target detection and identification, intelligence collection, and many other tasks that are involved in an operational mission. In practice, they often function together on such tasks, either alternating the conduct of a given task between each other or duplicating each other's efforts such as occurs when both crewmen look for targets in an area of interest.

The sharing of or alternating between tasks makes frequent but brief verbal communication between crewmembers a characteristic feature of AH-1 operational missions, and the same characteristic is expected to hold for AAH missions. However, since communications skills tend to break down under task overloads, effective crew coordination is dependent on each crewman's being highly proficient as the non-communication as well as the communication tasks he must perform. To the extent that a meaningful situational context and stress or tasks overload can be provided, the simulator is a suitable environment in which pilot-gunner procedural and cognitive communications skills can be developed under controlled, tutorial conditions.

Conclusions Concerning Pilot and Gunner Training Requirements

Analysis of the AAH pilot and gunner training requirements identified during the current study reinforces the view that an AAH simulator can play a major role in meeting those requirements. A suitably designed simulator, used in conjunction with an appropriate training program within a well-managed training system can provide a better qualified aircrew at a significantly lower cost than could be obtained through training exclusively in the AAH itself. In addition, training in such a simulator will increase flight safety, reduce the use of expensive missiles and other ordinances, reduce environmental pollution, and free terrain and other training resources for other uses.

Qualification Training. A major portion of projected AAH aircrew qualification training can be conducted in simulators. Based upon the review during this study of AH-1 training currently conducted at Fort Rucker, Alabama, it is estimated (subject to empirical validation when appropriate resources are available) that at least two-thirds and possibly three-quarters of the expected AAH transition training can be conducted in simulator training equipment such as that described in subsequent sections of this report. Such simulator training would emphasize the following training areas, with subsequent practice in the aircraft required only to build aircrew confidence and to verify that the necessary skill levels have been achieved:

emergency procedures

aircraft characteristics

aircraft limitations

cockpit procedures

takeoff to a hover

hovering flight

landing from a hover.

normal takeoff

high speed flight

normal approach

maximum performance takeoff

traffic pattern

steep approach

autorotation to touchdown (all airspeeds, altitudes)

maximum gross weight operations

quick-stop/deceleration maneuvers

instrument flight

radio communication

coordinated crew activities

all procedural tasks associated with navigation, weapons and target acquisition systems

In addition to the above, it is expected that such a simulator will be suitable for the aircrew's initial training in the following activities with additional training to be required in the AAH itself to assure that all associated training objectives have been fully met:

night missions

terrain navigation

terrain flight takeoff

terrain flight traffic patterns

terrain flight approaches

introduction to weapons use

range safety procedures

masking and unmasking techniques

Gunnery Training. Because of the high cost of gunnery practice, particularly where the expensive Hellfire missile is concerned, the use of a simulator for gunnery training is highly desirable. It is expected that the proposed AAH simulator can be used for the conduct of a significant portion of that training. It will be fully suitable for the introduction of the pilot and the gunner to the operational procedures associated with each on-board weapons system, and it is expected that relatively high proficiency levels can be reached through training in the simulator for each of them. Because of the inherent simplicity and accuracy of the Hellfire missile system, virtually full proficiency at its employment will be obtainable in the simulator, and firing live missiles from the aircraft will be required only to build confidence in the aircrews involved. For the other weapons systems, practice firing from the aircraft likely will be required in order to hone skills to combat proficiency levels, but practice in the simulator will greatly reduce the need for such in-flight training.

Instructor Pilot Training. Because of its configuration and flexibility, the AAH simulator will be an appropriate vehicle in which to

conduct major portions of AAH instructor pilot training, and will permit a greater degree of standardization of instructor performance than would be possible in the aircraft where instructors could not be observed directly. The aircraft itself will be required for the conduct of portions of the AAH instructor pilot's training, however.

Unit Training. The use of AAH simulators at Army aviation units will contribute significantly to aircrew proficiency at all of the tasks described above and can be expected to eliminate completely the need for Unit aviators to fly the aircraft solely for the purpose of developing, reacquiring or maintaining such proficiency. The simulators will be less useful, however, for training that would involve performance in conjunction with other combat elements. Therefore, the AAH aircraft will play a significant role in the training of Army aviators. It is expected, however, that the use of the AAH in support of ground unit training, plus the flying essential to exercise the aviation maintenance support system, will be fully sufficient to provide the training necessary to the maintenance of AAH pilot and gunner skills not amenable to maintenance in the proposed simulators.

VISUAL DISPLAY TRAINING CONSIDERATIONS

The preceding review of the training requirements associated with an AAH simulator indicates a clear need that the simulator have an extra-cockpit visual display. The need for such a display derives principally from the requirement to conduct simulator training related to four kinds or groups of tasks: (1) tasks related to aircraft handling; (2) tasks related to terrain flight navigations; (3) tasks related to target detection and identification; and (4) tasks related to target engagement.

The following discussion examines each of these kinds of training tasks and the suitability of model board, CGI, and film-based visual display systems with respect to each. It should be noted that this discussion is limited to training considerations. Other kinds of considerations affecting simulator visual display system design are addressed in Section IV.

Task 1: Aircraft Handling Tasks

This training requirement consists of the development of precise skill in controlling the position, attitude and movement of the AAH with respect to external objects and features of the environment. Most aircraft handling skills can be developed using the information available inside the cockpit, i.e., the instrument displays. The need for an extra-cockpit visual display arises when the tasks to be learned involved approaching stagefields, confined areas or other potential landing areas; maneuvering around or near natural or cultural objects or features such as occurs when hovering and during NOE flight; using environmental features for concealment or masking; and flying in formation with other helicopters. In all such cases, critical visual cues are those that permit the pilot trainee to determine distances to objects, clearances between objects, and closure rates. A wide variety of visual scenes is not a requirement for such training, e.g., a single stagefield and a relatively small NOE maneuver area would be sufficient for the full development of such skills. Since recognition of specific features of the environment and objects involved would not be a significant part of aircraft handling training, it would be feasible to conduct such training in a familiar visual environment.

Model Board Considerations: A model terrain board can provide the visual cue information needed for the conduct of aircraft handling training.

A board of modest size, e.g., representing a geographic area of from 15 to 25 square miles, would be sufficient and might include simulation of a stagefield or heliport with its associated visual cues with a surrounding area consisting of a variety of natural and cultural features in which NOE aircraft control tasks could be practiced. An important feature of such a model board display would be its information content, i.e., the amount of detail in which its features and objects were represented. A high level of detail would be required, and this would dictate a requirement for a relatively large model scale, e.g., probably greater than 1000:1, depending upon the techniques employed in board construction.

CGI Considerations: In concept, CGI visual displays can provide the information content and detail necessary to the conduct of aircraft handling training in a simulator, although the specific information to be programmed for display may not always be clear. In general, a CGI display modeled after the model board display described above would offer the kinds of training opportunities required. The amount of detail that would have to be displayed in a CGI scene of a simulated NOE maneuver area is not known and probably would have to be determined experimentally. Present state-of-the-art CGI displays are believed to be capable of displaying the required detail, however.

Film Considerations: Film is not considered to be a suitable medium for the generation of a visual display for use in the conduct of aircraft handling training. Because of the fixed nature of film, a film-based display would not be sufficiently responsive to changes in the aircraft position and attitude resulting from pilot control input.

Conclusion: Aircraft handling training requirements can be met using either model board or CGI visual display technology.

Task 2: Terrain Flight Navigation Tasks

The navigation tasks of concern to the AAH pilot consist of relating map symbols and features to objects and features of the visual world as seen by the pilot at contour and NOE flight levels. Therefore, a realistic presentation of those features, in sufficient variety, is a basic requirement of a simulator that is to be used for navigation training.

Model Board Consideration: The adequacy of a model terrain board visual display for the presentation of environmental features suitable for navigation training is limited by the size and scale of the geographic area simulated, the information content of the board, and the depth of field of the optical system employed. The present state of the art will permit, at least in concept, the development of a board of adequate size, scale and information content for realistic navigation training. As a practical matter, since the very nature of the navigation task necessitates a considerable variety of training situations, the cost of building, housing, and operating a board large enough to provide sufficient variety of the features needed for navigational training, and to provide those features at a reasonable scale, may well be prohibitive. Using present day optics, depth of field limitations pose an additional and serious problem for navigation training, since navigation at terrain flight levels is dependent upon the identification of geographic features in both near and far fields. Because of these considerations, the navigation training value to be derived from model board visual simulation is limited.

CGI Considerations: Present day CGI displays, as well as those forecast for the next 2-3 years, offer very little training potential for terrain flight navigation. Since present CGI technology permits only gross and/or symbolic representation of visual scenes, such a display could not be used to provide the necessary training. The navigation task as presented in a simulator with a CGI display would consist of relating map symbols to visual display symbols rather than to features of the visual world. Training to identify such relationships in the simulator would not be expected to transfer to the task required to navigate in the operational environment, because the task of relating CGI display symbols to terrain features as seen from low altitudes would remain to be trained. Except possibly for minor procedural elements of terrain flight navigation, such as map manipulation and orientation, CGI technology expected to be available within the next few years would appear to hold little promise for navigation training.

Film Considerations: The use of cinematic methods to teach navigation skills and geographic orientation has been thoroughly explored and has been found to be a satisfactory method for training terrain navigation (McGrath, 1973). Its chief limitation lies in the fact that it does not permit closed-loop exploration of a geographic area, and therefore does not permit practice of navigation per se. Gainer and Sullivan (1976a) have noted, however, that this is not a serious deficiency in the use of film-based media for NOE navigation training, since the fundamental skills and knowledge needed for performance of the terrain navigation task involve detecting and identifying various types of preselected navigational checkpoints, interpreting terrain forms, relating sighted features to those

portrayed on a map, and making navigational decisions. These skills and knowledges can be developed using still and motion pictures.

Conclusion: The visual training necessary for successful terrain flight navigation in the operational environment can best be provided using a library of wide-angle films in conjunction with appropriate instructional procedures and practical exercises, followed with limited confirmatory practice in a non-simulated environment. Navigation training of much more limited scope would be possible in a simulator with a relatively large model board display. Training involving a CGI display would be of little, if any, value.

Task 3: Target Detection and Identification Tasks

The tasks of detecting and identifying targets is dependent upon being able to see those targets and their distinguishing characteristics. Further, they must be seen at ranges that equal or exceed the ranges at which they are to be engaged. The principal characteristics of a visual display suitable for such training relate to the clarity of images of targets at simulated engagement ranges.

Model Board Considerations: The principal limitations of model board visual simulation with respect to target detection and identification are the resolution of the display and depth of field. Depth of field, or focus, is a problem in a simulated tactical environment where near focus is required in order to avoid striking objects used for concealment or masking, while at the same time, far focus is needed to view distant objects. With respect to resolution, examination of existing model board displays indicates that, regardless of overall model board scale or the number of display TV line pairs, identification of targets, even large

targets such as tanks, at ranges appropriate for their tactical engagement is not possible. Even detection of the presence of such objects at appropriate ranges is impossible, and the use of oversized models which would aid detection is not desirable where close approaches to such targets would occur during other training exercises. Therefore, adequate training for tasks involving target detection and identification in a simulated tactical context cannot be provided using the model board approach.

CGI Considerations: With compromised (enhanced) scale, color, contrast and/or brightness of targets when they appear at far ranges, it is possible to assure target detection with a CGI display. There is a danger in this approach, however, in as much as many of the cues to detection employed in a non-simulated tactical environment cannot be represented appropriately, given the present state of the art of CGI technology. Training aviators to pick out targets from among the background clutter at specified engagement ranges using detection cues that must be employed tactically (e.g., shapes, relative size, light dust and smoke trails, small movements) cannot be done well if at all. Instead, detection would have to be made a very easy task through distortion and exaggeration of these target signatures and characteristics so that the detection task would become basically unlike that required operationally. Sufficient target detail to be used for target identification training could be provided by CGI, but if appropriate scale were maintained, the resolution of the display would limit the value of such training.

Film Considerations: Film media can provide scene content and image quality appropriate to target detection and identification training, but at the sacrifice of closed-loop maneuverability of the simulated flight vehicle.

This approach becomes feasible in a part-task training device where the flight path can be fixed and filmed in advance, or in a classroom situation where a wide range of still and motion picture views of targets in tactical situations can be presented inexpensively in conjunction with appropriate training procedures and techniques.

Conclusion: The model board has little merit as a medium for target detection and identification training in the AAH simulator. CGI is preferable to a model board for this training requirement, but the deficiencies are still such that the value of the training provided would be suspect. Film is the best available simulation medium for this training. Target detection and identification training should be provided in part-task trainers not providing closed-loop control over the simulated aircraft's flight path or in a classroom environment.

Task 4: Target Engagement Tasks

The visual elements of the target engagement task consist of maneuvering the AAH into an attack position, acquiring the target, tracking the target during the period of weapon release or missile flight, making adjustments in aim based upon weapons impact point, and assessing target damage. Those elements of the task related to aircraft handling, maneuvering with respect to mask and cover in the NOE environment, and target detection and identification are discussed above.

Model Board Considerations: The use of a terrain board visual display for target engagement training would be constrained primarily by three factors: (1) target variety would be limited to a relatively small set in fixed locations on the board, and target movement would be severely restricted; (2) engagement ranges would be restricted to ranges at which

the targets could be detected, and these ranges typically would be less than the ranges suitable for engagements in an operational situation; and (3) there would be little or no capability to provide feedback to the pilot concerning the accuracy and effectiveness of his weapons except through artificial means, e.g., numerical scores, and the visual effects of weapons firing would have to be generated electronically for superimposition upon the model board display. An additional constraint would be the need to relate visual display information with cockpit displays depicting radar and infrared views of the same areas and magnification of those views.

CGI Considerations: CGI technology could provide a visual display suitable for the conduct of target engagement training activities and would not share many of the constraints of the model board approach. Targets could be engaged at realistic ranges, and a considerable variety of target types and positions could be simulated. Weapons effectiveness could be represented, at least symbolically, and weapons signatures could be provided without additional hardware. CGI displays would be constrained, however, by the artificiality of appearance of current state-of-the-art CGI display scenes, and the limitation discussed elsewhere concerning target detection and identification would be of concern.

Film Considerations: There are three primary constraints with respect to the use of film as a visual display medium in target engagement training: (1) training involving closed-loop control of the simulated flight path would be precluded because of the fixed nature of the display; (2) feedback concerning weapons accuracy and effectiveness would be restricted much as it would using a model board display; and (3) correlation of film displays with IR and TV displays would present a complex, although solvable, techni-

cal problem. The first of these considerations, the fixed flight path, is not a major problem, since most target engagement activities can be performed while flying a pre-selected flight path. The latter two considerations are of more concern. The problem of correlating cinematic with IR and TV displays could be costly to solve.

<u>Conclusion</u>: Except to the extent that closed loop maneuverability and IR and TV display correlation would be required, a cinematic visual display is the display of choice. The second choice overall and the first choice for target engagement training where the simultaneous task of maintaining control over the flight of the aircraft is desired is the CGI display. Use of a model board display would impose severe constraints upon target engagement training, primarily because of the unrealistic engagement ranges that would be necessary for some weapons systems.

Summary of Display Type Considerations

There is no clear choice of a visual display system for the AAH simulator. In fact, none of the display types considered here is even minimally suitable for all the required training. Instead, the advantages and disadvantages of each type with respect to the training discussed above suggest that a simulator with a mix of visual displays would possibly be the best solution. Even then, however, it is clear that the present state

of the visual simulation art will not permit the full range of training for AAH visual flight tasks to be conducted in a simulator. At best, the AAH simulator will be a part-task training device with respect to visual training requirements. A significant portion of AAH training will have to be conducted in flight where real-world visual cues can be employed.

Since no single solution is available, it would be well to consider multiple solutions, each optimized, so far as the state of the art will permit, to particular training requirements. Such an approach would lead to design of a system of simulators or training devices rather than to a single, all-purpose, full-mission simulator in which only those training activities suitable to the visual display system selected could be conducted. Such an approach would permit a greater proportion of AAH training to be conducted in simulation, and, as a consequence, would reduce the total requirement for use of the AAH itself for such training.

There are advantages to the use of cinematic visual displays in meeting some of the AAH visual training requirements. In fact, film can be the medium of choice for two or three of the four kinds of training tasks discussed above, i.e., terrain navigation, target detection and identification, and possibly target engagement. Therefore, consideration must be given to a simulator in which training in these tasks could be conducted. At the same time, however, a film-based display would be totally unsuitable for the conduct of aircraft handling training, so a simulator with a model board or CGI display would be required for it.

The design of an AAH pilot and gunner simulator system that would meet the diverse visual display requirements discussed above is described in Sections IV and V.

MOTION SYSTEM TRAINING CONSIDERATIONS

The Role of Motion in Simulator Training

It is recognized that the AAH is capable of movement in three rotational (pitch, roll, yaw) and three translational (vertical, lateral, longitudinal) axes, and that it is possible for an experienced pilot to distinguish movement associated with each axis under optimum conditions. These facts to not necessarily dictate the motion system design necessary for effective simulator training, however. Direct and indirect costs associated with procuring and operating simulators with large excursion, six-axis motion systems are very high, and economy in motion system procurement is desirable. One large user of flight simulators has recently decided to forego platform motion systems on its newer simulators in order to reduce the cost and complexity of required visual systems. While the elimination of motion in an AAH simulator would not seem productive, it is certainly desirable to examine the need for AAH simulator motion and to make sure that the simulator's motion systems are appropriate to the training requirements. Otherwise, there is a danger that a simulator motion system might be procured that is modeled after aircraft motion without regard to training needs per se. The fact that the AAH moves in a certain manner is insufficient reason to design a training simulator that moves the same way. The effects of movement upon pilot and gunner performance are the critical factors. Investigation of the influence of motion upon transfer of simulator training to operational aircraft has been largely ignored. There were a number of studies of simulator motion in relation to aircraft handling qualities and control during the 1950s and 1960s, but most of them addressed transfer of training only indirectly. The first significant published transfer of

training study of the effectiveness of simulator motion upon subsequent performance in flight was reported in 1975 by Jacobs and Roscoe.

Jacobs and Roscoe reported that pilot performance in the aircraft did not benefit from the presence of normal washout cockpit motion in the simulator. In that study, training received in the GAT-2 in a two-axis (pitch and roll) normal washout motion condition, compared with training in the same device without motion, resulted in non-significant differences in amount of transfer to the aircraft for those two conditions. There was, however, significant positive transfer for both motion and no-motion conditions. Similar results have been obtained in a U.S. Air Force undergraduate pilot training study involving the more sophisticated six-axis motion system associated with the Advanced Simulator for Pilot Training (ASPT)(Woodruff, 1976).

The finding in these two recent studies that the presence of motion did not increase simulator training effectiveness is of considerable interest, since there are other studies showing that, at least under some circumstances, motion does influence simulator training. For example, Fedderson (1962) reported a slight advantage in favor of a motion simulator trained group over a no-motion group during brief transfer trials hovering a helicopter. More importantly, perhaps, the motion group in his study reached asymptotic performance in the simulator more rapidly, suggesting that simulators with motion may provide more efficient training. A recent U.S. Air Force study of pilot responses to engine failure in a simulated transport-type aircraft found that training is more effective when motion is added to a simulator with a visual display than when the same simulator and visual are used without motion (DeBerg, McFarland & Showalter, 1976).

Further, there is evidence that pilot performance in the simulator differs as a function of the presence or absence of motion. For example, Perry and Naish (1964) found that pilots respond to external forcing functions such as side gusts more rapidly, with more authority, and in a more precise manner in a simulator with motion and visual cues than when only visual cues are present. NASA researchers (Rathert, Creer & Sadoff, 1961) found that the correlation between pilot performance in an aircraft and in a simulator increased with the addition of simulator motion cues where such cues help the pilot in coping with a highly damped or unstable vehicle or a sluggish control system, or under some circumstances, where the control system is too sensitive. Where the aircraft is easy to fly, however, as is the case with the aircraft used in the Jacobs and Roscoe study (Piper Cherokee) and in the Air Force ASPT study (T-37), motion may have no effect. In another NASA study (Douvillier, Turner, McLean & Heinle, 1960) of the effects of simulator motion on pilot's performance of flight tracking tasks, the results from a moving base flight simulator resembled the results from flight much more than did those from a motionless simulator. In a British study, Huddleston and Rolfe (1971) reported that the presence of a simulator motion produced patterns of control response more closely related to those employed in flight. That is, using simulators without motion, experienced pilots were able to achieve acceptable levels of performance, but their patterns of control response showed that their performance was achieved using a strategy different from that used in a dynamic training environment. Research at the University of Illinois related to instrument display design responses to display types differentially, with inappropriate banking motions interfering with command flight path tracking (Ince, Williges, & Roscoe, 1975). ?

Thus, numerous studies provide evidence that the presence of motion, i.e., movement of the platform upon which the simulator cockpit rests, does affect performance in the simulator. Not only can motion affect learning rates, but the performance of the pilot in the presence of motion may be different than it would be in the absence of motion. With motion, his simulator control responses to external forcing functions appear to be more rapid and accurate and more like responses used to control the aircraft in flight. While it cannot be concluded from these studies that simulator motion during training will enhance subsequent performance in the aircraft, they do suggest that simulator motion can affect the acquisition of skills in the simulator. These effects of motion upon performance in the simulator have been demonstrated under controlled experimental conditions that tend to make it unlikely that the noted differences in performance could be attributed solely to factors other than the presence of motion during simulator training.

The influence of platform motion is not necessarily always beneficial, however. Excessive or inappropriate motion, e.g., high levels of simulated turbulence, could make learning less rapid if it were a factor in making the simulator more difficult to control. Likewise, motion that is out of synchronization with visual or other cues could interfere with simulator control if it made trainees ill or presented misinformation to them. For example, it has been reported that the simulator used in the Air Force ASPT study cited above has time lags in the motion system that make the performance of some maneuvers difficult (Hutton, Burke, Englehart, Wilson, Romaglia, & Schneider, 1976).

Maneuver vs. Disturbance Motion

In discussing the influence of motion upon pilot performance in simulators, Gundry (1976a, 1976b) distinguishes between two kinds of motion cues and suggests that they might affect performance differentially. Maneuver motion is that motion that arises within the control loop and results from a pilot-initiated change in the motion of the aircraft in order to change its heading, altitude, or attitude. Disturbance motion, on the other hand, arises outside the control loop and results from turbulence or from failure of a component of the airframe, equipment or engines that causes an unexpected (to the pilot) motion of the aircraft. Matheny (1976) made a similar distinction in a study in which he identified aircraft motion as resulting from external forcing functions or from input into the aircraft controls.

The reason that platform motion can result in quicker, more accurate simulator control probably is that the disturbance component of that motion resulting from simulated turbulence or equipment failure can provide more rapid and relevant alerting cues about forces acting upon the aircraft than can be obtained from other cue sources. Maneuver motion does not fulfill an alerting function, because it results from pilot-initiated control movements. Research involving maneuver motion, Gundry states, indicates that this component of platform motion has little effect upon the control of an aircraft whose flight dynamics are stable. For unstable vehicles, however, the presence of maneuver motion will allow the pilot to maintain control even in flight regions where control by visual cues alone would be impossible. Thus, disturbance motion permits more rapid and accurate aircraft control under all flight conditions in which such motion is appropriate. Maneuver motion, however, improves aircraft control only when the aircraft is unstable.

In both the Jacobs and Roscoe and the Air Force ASPT studies cited above, emphasis was upon simulation of maneuver rather than disturbance motion. Since maneuver motion is pilot induced and the aircraft involved in these studies were quite stable, the most likely role of motion was to provide confirmatory feedback to the pilot. If sufficient feedback were available from other sources such as the aircraft instruments or an extra-cockpit visual display, as likely was the case, the maneuver motion provided in these two studies could not be expected to have a large effect upon simulator training effectiveness, and probably would be ignored altogether by the trainees. Had these two studies examined the influence of disturbance motion resulting from factors outside the control loop, e.g., malfunctions, the results probably would have been different. The evidence that disturbance motion may have a large effect upon pilot performance in the aircraft should not be overlooked in the design of an AAH simulator.

The influence of platform motion upon transfer of simulator training has not been clearly established by the data available at the present time. It has been demonstrated that motion can affect pilot performance in the simulator in ways that may make his performance in the simulator more like his performance in the aircraft, but it has not been shown that simulator motion enhances his subsequent performance in the aircraft. The two studies that have addressed the question of transfer directly did not support a conclusion that motion is needed. Likewise, there is no consensus among pilots as to the need for motion in simulator training.

More attention has been paid in the design of existing simulators to maneuver motion than to disturbance motion. Emphasis has been upon providing in a simulator the motion cues associated with well-coordinated pilot control inputs, scaled down to the limits of travel and accelerations of

the motion platform. Since most training and operational aircraft are relatively stable, this kind of motion simulation may be of very little potential value in training. It would be more beneficial from the training standpoint to provide the motion cues associated with disturbance to the aircraft not originated by the pilot, and then only at initial suprathreshold onset values, so that he could learn to respond specifically to motion cues rather than learning to respond to visual or other cues that occur later in time.

The distinction between maneuver and disturbance motion is useful in attempting to understand both the prior research on motion and the reactions of pilots to the motion component of aircraft simulators. In the transfer of training studies in which motion did not appear to influence subsequent pilot performance, the motion involved was predominantly, if not exclusively, of the maneuver variety. On the other hand, disturbance motion was the predominant type of motion in studies in which changes in pilot performance were related to motion simulation. Thus, the results of both sets of studies can be accepted and attributed to the nature of the motion simulation involved in each. Disturbance motion is important, at least in training situations where disturbance cues can be related to specific training objectives and when the aircraft simulated is unstable or is particularly responsive to control input. Maneuver motion may be important also under some circumstances, but the evidence available at this time has not shown that it contributes to transfer of training in easy-to-fly aircraft.

Motion Characteristics of the AAH

In considering the need for and performance characteristics of motion systems for an AAH simulator to be used for training, it is helpful to

distinguish between the two kinds of motion discussed above, i.e., maneuver motion and disturbance motion, and to identify the training needs associated with each.

AAH Maneuver Motion. During flight at airspeeds above translational lift, the AAH is a stable, easy to control aircraft. The handling characteristics of the AAH, as reported by pilots who participated in the YAH-64 operational tests, are comparable to other helicopters. The aircraft reportedly handles very much like the AH-1 Cobra, and the pilot's workload is comparable. An initial pilot reaction is that it is more of a challenge to fly, but this apparently is due to its greater size. Possibly because of its size, the AAH tends to be somewhat more stable in flight than the AH-1. There is a pitch up in attitude during normal takeoff that occurs at about 40K, but the primary cue to this change is visual rather than motion since it does not occur abruptly, and correcting for it presents no particular training problem. Attitude changes that occur during pilot induced maneuvers, such as rapid deceleration, steep turns, and autorotation, are directly responsive to pilot inputs and present no unusual control problems.

Although the AAH has freedom of movement with respect to each of the six motion axes during such flight, the cues associated with this motion do no more than confirm to the pilot what he already knows, i.e., that the aircraft has responded to his control input. Consequently, these cues are not necessary to precise control of the aircraft and have no demonstrated training value. It is likely that the pilot would frequently even be unaware of the presence (or absence) of maneuver motion cues during flight at airspeeds above translational lift, since those cues would be compatible with information he already has. In fact, there have been numerous

anecdotal reports of pilots not knowing whether the simulator's platform motion was on or off during training periods when only maneuver motion was simulated.

When taxiing and operating in ground effect, on the other hand, the AAH is relatively unstable. In order to taxi, power must be applied to lighten pressure on the wheels. When this is done, the aircraft tends to "fishtail" (yaw) and roll due to torque and to the fact that the tail rotor is located above the CG. The roll is most pronounced during turns and is of magnitude of approximately 3° to 4°. The roll is felt by the pilot, since it occurs rapidly, and a rapid correcting response is required in order to maintain directional control.

In the hover mode of operation, the pilot must use motion cues as the primary or initial source of information about changes in the position, movement, and attitude of the aircraft. Visual cues that would reflect these small but rapidly occuring changes tend to be noted by the pilot later than motion cues and thus would be inadequate for aircraft control. In fact, the pilot would be very likely to be unable to learn to hover the AAH in a simulator that lacked maneuver motion cues simulated through a platform motion system. Such a learning task would be comparable to learning to balance on a unicycle without being able to feel the onset of an imbalance condition. Visual cues alone would be insufficient for efficient learning to take place.

When taxiing and operating within ground effect, the sensitivity of the AAH to control input is such that the onset of motion resulting from pilot control input is prompt, and motion acceleration is rapid, particularly with respect to rotational movements. The magnitude of motion tends to be small, however, because large movements must be prevented to preclude

contact with external objects and/or the terrain. Consequently, in simulating maneuver motions of the AAH, particular attention should be directed to rapid motion onset and acceleration, but large displacement would not appear required. (Large displacements with respect to maneuver motion occur in flight above translational lift, but the research literature, as described above, does not indicate a need for such motion in a training simulator.)

It must be concluded that the magnitude of excursion of motion in an AAH simulator is less important than the promptness of such motion. Time lags between pilot control input and vehicle response that exceed corresponding lags in the AAH when operating in ground effect would have an adverse effect upon pilot performance, since the consequence would be loss of the early alert to the pilot that the cues associated with such vehicle motion provide. In that regard, it should be noted that the human body cannot perceive motion directly; it is sensitive only to higher order derivatives such as acceleration and jolt (Kinkade & Wheaton, 1972).

It is not possible, on the basis of available behavioral and training research data, to quantify precisely the excursions required in each degree of freedom in order to provide the maneuver motion cues appropriate to training pilots to taxi and hover the AAH. It is clear that time lags between control input and the onset of vehicle motion must approximate those of the aircraft itself. The rate of motion onset must be sufficient to alert the pilot, but greater rates probably add nothing to a simulator's training value. Rotational and translational displacements are unimportant in themselves. Displacement sufficient to permit the required alerting, plus provision for washout effects, is believed appropriate and sufficient. Quantitative specification of the relevant onset lags, rates, and displacements appropriate to the proposed AAH simulator are presented elsewhere.

Although designed to withstand 3 to 3.5 g's, the mission of the AAH will seldom subject it to these forces. During abrupt maneuvers at high airspeeds, it is possible for sustained g-forces to increase to the point that they are quite noticeable to the pilot. Since they occur as a function of pilot control input, they must be considered to be maneuver motions. Sustained g-forces cannot be simulated through available simulator motion platforms systems.

G-seats that can redistribute pressures on the pilot's body (within limits) have been used in simulators for high performance aircraft and generally have been endorsed by pilots as providing usable cues in the simulator to control of g-forces. They report that g-forces simulated in this manner provide cues that alert them to attend to the g-meter to avoid overstressing the aircraft. Even pilots who "like" g-seats for simulator training question their value with respect to transfer of training to the aircraft, however. Research by the Air Force involving the ASPT, in which the cue-value of a g-seat was examined, found no evidence that simulated g's affected pilot performance. NASA research involving simulation of g-forces with a centrifuge concluded that there was little need to simulate sustained g-forces in a simulator unless levels of acceleration stress greater than about 4g are anticipated (Rathert, et al., 1961).

In view of the lack of evidence that available and feasible kinds of g-simulation devices will contribute to the training effectiveness of an AAH simulator, no provision for sustained g-force simulation is included in the proposed simulator.

AAH Disturbance Motion. There are a number of events outside the pilot's control loop, or external forcing functions, that result in motion of the AAH that is unexpected by the pilot. These motions provide a degree

of realism to helicopter simulation (e.g., the shakes and vibrations that characterize helicopter flight under normal conditions and that experience has shown to be necessary to the maintenance of pilot vigilance), provide prompt cues to the need for action to overcome the effects of equipment failure (e.g., the sudden yaw that accompanies failure of the tail rotor pitch control system), and influence training problem difficulty (e.g., simulated turbulence makes precise aircraft control more difficult).

There are two kinds of disturbance motion that should be provided in an AAH simulator. Uncorrelated disturbance motion, the first kind, is low frequency motion that is not correlated with pilot control movements or visual displays and appears to the aircrew to be either irregular in occurrence and essentially random in frequency, direction, and amplitude; or to be of a relatively fixed frequency, direction, and amplitude but to be virtually always present. Turbulence and oscillatory shakes are examples of uncorrelated disturbance motion. These motions do not present a cue that the pilot must learn to discriminate from other similar cues in order to initiate a particular control input. For this reason, simulation of uncorrelated motion can be relatively gross with respect to corresponding motion in the aircraft but should be present in the simulator under circumstances which characterize its presence in the aircraft.

Correlated motion, the second kind of disturbance motion of concern in AAH simulation, is motion that is a consequence of events that are of immediate interest to the pilot and require his prompt attention. The pilot must be trained to discriminate among correlated disturbance motion cues in order to make an appropriate response. Accurate simulation of disturbance motion cues within the limits of the pilot to make the necessary discrimination is important to effective simulator training.

Motion that results from an equipment failure or sudden (and unintended) change in configuration of the aircraft, such as damper failure or asymmetrical external stores hangup or jettison, is illustrative of a correlated disturbance motion. Its characteristic is a rapid onset or jolt that has a characteristic and predictable effect on the performance of the aircraft. The pilot must learn to respond to such motion by rapidly identifying its probable cause in order to initiate an appropriate emergency procedure, and must rapidly make an input to the aircraft's controls that will allow him to maintain control over the vehicle's flight.

Correlated disturbance motion cues that should be provided in an AAH training simulator include motion cues that result from each of the aircraft failures and malfunctions that will be identified in the AAH flight manual when that document is prepared. Since the final configuration and flight characteristics of the aircraft are not known at the present time, these malfunctions cannot be listed here. In addition, motion cues correlated with the following disturbing events should be provided in the AAH simulator: buffets, blade stall, blade imbalance, blades out of track, touchdown impact, stores release, weapons firing, blade strikes, tail assembly strikes, wheel strikes, and projectile impacts on the airframe and blades. Motion cues uncorrelated with specific events that should be included in the AAH simulator include turbulence and the general vibrations and oscillations associated with routine helicopter operation.

Disturbance cues in the simulator that are correlated with specific events should faithfully reproduce the cues that are caused by similar events in the aircraft with respect to time and onset rates for the same reasons discussed above related to maneuver motion cues. Likewise, unless magnitude of excursion is a significant cue that enables the pilot to

determine the event with which the disturbance is correlated, these cues can be of relatively low magnitude, since it is the acceleration or jolt that provides information to the pilot that is useful in training. Quantitative specification of the relevant onset lags, rates, and displacements appropriate to the proposed AAH simulator are presented elsewhere.

Motion Requirements for AAH Gunner Training

The preceding discussion of AAH motion simulation has emphasized the requirements related to pilot tasks and the discriminations that pilots must be trained to make among motion cues. The gunner is not in the pilot's control loop, so some motions that are confirmatory to the pilot may be unexpected to the gunner. It is therefore desirable to examine the influence of motion upon the performance of the gunner during operational missions in the AAH.

There are few aircraft motions that could be considered maneuver motions so far as the gunner is concerned. The only change in movement of the aircraft through space attributable to gunner activity results from a weapons recoil effect upon the airframe. This effect is a jolt that confirms that the weapon has fired, but it has no other training value, since the gunner is not required to learn to distinguish it from other motions. The chief advantage of providing motion associated with weapons release is to add a degree of realism that could contribute to the perceived worth of the device.

The gunner can be expected to experience all of the disturbance cues experienced by the pilot. Those that are correlated with specific events related to equipment malfunctions or emergency situations will be of little training value to the gunner, except to the extent that he must take

corrective action himself or that they may enable him to assist the pilot in their discrimination and identification. The gunner will have been trained to discriminate and identify these latter motions during his training as an AAH pilot, however. Uncorrelated disturbance cues, i.e., representative helicopter vibrations and oscillations and the effects of turbulence, will contribute to the realism and influence the difficulty of the gunner's task, but they will not provide cues he must learn to discriminate.

The amount of physical displacement of his cockpit can affect the gunner's operation of his weapons, sensing, and target detection systems. Tuning his IR or TV display, for example, will be more difficult in heavy turbulence than in smooth air. Heavy turbulence can also affect the difficulty of the tasks involved in operation of the TADS and aiming and firing the flexible fire weapons and missiles, although these systems are shock mounted and optimally designed to permit their smooth and effective operation from a moving platform. Normal operation of the helicopter at an altitude of several hundred feet involving steep bank and pitch angles would have little effect upon the effective use of these well established systems, and gunner training in their effective use does not require a device in which large excursions are simulated.

The motion requirements for effective training of the AAH gunner are to provide the shakes, vibrations and oscillations associated with normal helicopter operation, light to moderate levels of turbulence appropriate to the operational environment of the AAH, jolts associated with weapons firing, and the disturbance motion cues correlated with any equipment failure or malfunction to which the gunner must learn to respond in concert with the AAH pilot. Excursions can be small, and motion onset times are important only with respect to jolts associated with weapons firing and

the few motions that must be correlated with equipment failure that involve direct action by the gunner. Motion onset rates adequate to simulation of uncorrelated disturbance motion and jolts will be required. Quantitative specifications of the requirements for motion simulation for AAH gunner training are presented elsewhere.

SECTION III

A RECOMMENDED AAH SIMULATOR TRAINING SYSTEM

This section of the report describes the AAH training system that has been conceptualized during the conduct of the AH-64 Flight and Weapons Simulator Concept Formulation Study. The training system is responsive to the training requirements described above. At the same time, constraints upon system design imposed by non-training factors have been taken into consideration. In some instances, it has been necessary to adopt concepts that might be judged less than optimum from the training standpoint in order to avoid much more costly alternative concepts. Overall, it is believed that the simulator training system described below will provide optimum school and unit level training for AAH pilots and gunners in conjunction with other Army training resources.

It is important to note that the AAH itself is a principal resource that will play a large role in AAH aircrew training. In selecting simulator design concepts, the unique value of training in the aircraft in an operational or simulated tactical environment was taken into account. No attempt has been made to design simulators that would eliminate completely the need for the aircraft, although the system described below can reduce the role of the aircraft in training virtually to that of building the confidence of pilots and gunners with respect to their simulator-acquired skills, integrating those skills with others that have been acquired elsewhere, and broadening the base of experience in the performance of tasks for which only limited variety can be provided economically through simulation.

The principal deficiencies in the training that can be provided through simulation, and that therefore should be the subject of further practice in the aircraft, are related to operationally oriented visual skills. These include visually acquiring, identifying, and engaging targets at maximum weapons ranges, damage assessment, assessment of and interaction with a dynamic tactical situation, coordinated attacks involving visual reference to other (friendly) attacking units, and operations at night under battlefield illumination. While the basic skills underlying these kinds of operationally oriented tasks can be developed to criterion levels of proficiency in the proposed AAH simulator, and the operational tasks themselves can be introduced and practiced in the device, use of the aircraft for the integration and refinement of these skills is believed to represent a cost effective use of the aircraft in conjunction with other training resources.

OVERVIEW OF THE RECOMMENDED AAH SIMULATOR TRAINING SYSTEM

The AAH simulator training system that has been conceptualized during the present study consists of two simulators with unique characteristics designed to provide training that is minimally constrained by limitations in current simulator technology while at the same time providing the maximum amount of effective training that technology will permit at an acceptable cost. The two simulators are: (1) an AAH Mission Trainer (MT); and (2) an AAH Navigation and Systems Procedure Trainer (NSPT). These two simulators are described schematically in Figure 1.

The MT and the NSPT consist of the principal components described below. A full description of each component and its functional capabilities

is presented in subsequent sections of this report.

AAH Mission Trainer (MT)

- A pilot and gunner trainee station that replicates the location, cockpit, interior, displays, and controls associated with these two cockpit positions in the aircraft.

- An instructor station located remotely but in proximity to the cockpit module. The instructor will be provided displays and controls that permit him to monitor performance of both the pilot and copilot/gunner, including displays of the TADS, PNVS, and IHADSS presentations that are visible to both crewmen. In addition, controls will be provided to enable the instructor to control the training program, and also to operate the Mission Trainer when gunner-only training is in progress.

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- An additional instructor position and two observer positions adjacent to the instructor position. From this position, the observers will be able to see the instructor's displays and controls and will be able to monitor the training activities underway.

- A motion system that will provide the maneuver and disturbance cues necessary to the training underway.

- A separate vibration or "shaker" motion system mounted on the motion platform. This shaker motion system will provide disturbance cues through the pilot and gunner seats and controls that are of inappropriate frequencies for efficient operation of the primary motion system.

- A wide-angle visual system that will project computer generated visual scenes appropriate to the pilot and gunner training activities to be conducted in the MT on a cylindrical direct viewing screen located off of the motion system.

• A computer and its associated peripheral and interface equipment needed to operate the MT in real time.

AAH Navigation and System Procedure Trainer (NSPT)

• A gunner trainee station that replicates the cockpit interior, displays, and controls associated with the forward cockpit in the aircraft.

• An instructor station located immediately to the right-rear of the gunner. From his position, the instructor will have a direct view of the gunner and his controls and cockpit displays and of the extra-cockpit visual display. Controls and associated displays that will permit the instructor to operate the NSPT and to control the training program will be conveniently located for his use.

• An observer or instructor trainee position adjacent to the instructor station. From this position, an observer will be able to monitor the instructor displays and controls and will be able to observe the training underway.

• A vibration or "shaker" motion system that will provide disturbance cues through the gunner's seats and controls.

• A wide-angle visual system that will project a cinematic visual scene appropriate to navigation and target detection and engagement training on a flat direct viewing screen.

• A computer and its associated peripheral and interface equipment needed to operate the NSPT in real time.

SCOPE OF MT AND NSPT TRAINING

The training that will be required for AAH aircrews has been discussed in Section II of this report. It consists of aircraft qualification training, gunnery training, and training in the operational employment of the

AAH as a weapons system. The concepts of employment of the MT and the NSPT in the conduct of the required training are described below.

During AAH qualification training, all trainees will receive the same training irrespective of whether their initial post-qualification assignment will be as a pilot or as a gunner. Although there will be a degree of specialization between pilots and gunners at the operational unit level, it is assumed that each AAH aircrewman will be required to maintain a degree of proficiency as both a pilot and a gunner. Consequently, the simulator training of an AAH crewman will consist of his training as both a pilot and a gunner. While the following discussion distinguishes between pilot training and gunner training, it should be understood that each trainee will be trained to function effectively in both roles, and that both pilots and gunners will receive training in both the MT and the NSPT.

Training in the Mission Trainer

As its name suggests, the MT will be used for the full mission training of an AAH pilot and gunner. All AAH systems operated by the two crewmen from their respective cockpits will be simulated, and the proficient operation of these systems will be the goal of training in the device. In addition, MT training will encompass those areas in which the crew must function in coordination with each other and with other simulated friendly units.

The MT will be comparable to other high fidelity, visually equipped flight simulators with respect to pilot training. In it, the pilot will be able to develop the full range of skills required for his basic qualification in the aircraft, including execution of normal and emergency procedures, and aircraft operation and control during taxi, hover and flight under instrument

and visual conditions. In addition, the device will be used for instrument flight training and retraining for AAH-qualified aviators and for the maintenance of high levels of proficiency of all aircraft operation and control skills associated with maintenance of combat readiness.

The principal limitation of the MT with respect to pilot training will relate to the visual display. The CGI display will not permit the full range of visual task training that will be required of the AAH pilot in a tactical environment. (Limitations of the CGI type of visual display are described in Section II of this report.) Consequently, visual tasks involving terrain flight navigation and target detection and identification will not be trained in the MT. Pilots will receive training related to these visual tasks, as will the gunner, in the NSPT.

Much of the training of the AAH pilot in the MT, particularly during his initial qualification in the aircraft, can be conducted more efficiently on an individual basis. For example, developing skill in aircraft control does not require the active participation of the gunner under normal conditions. Therefore, while the pilot is undergoing such training in the MT, the gunner will be undergoing separate training in the NSPT.

Prior to his training in the front or gunner seat of the MT, each gunner trainee will have undergone training in the back seat of the device. In addition, he will have undergone training in the NSPT that will make him familiar with the operation of the controls and displays associated with the gunner's position in the AAH. Therefore, emphasis in the MS training of the gunner will be upon non-procedural aspects of the operation of the sensor and weapon systems available to him in that device and upon training to function as a gunner in an integrated AAH crew.

Training in the Navigation and Systems Procedures Trainer

The NSPT will be the primary training equipment with respect to the training of AAH aircrewmen to perform all terrain flight navigation tasks that are amenable to training in an open-loop situation, i.e., where maneuvering of the aircraft is not a requirement. A front cockpit simulator is an appropriate device for the conduct of such training, since its occupant, the gunner, normally does not control directly the flight of the aircraft. In addition, such a device is suitable for the conduct of training for procedural tasks normally performed only by the gunner. These gunner tasks include performance of aircraft checklist front cockpit procedural tasks as well as set-up and procedural operation of the indirect viewing, target designation, missile coding, and other equipment located in the front cockpit area of the AAH.

Because of the advantages discussed in Section II of the NSPT's cinematic visual display for certain visual task training, this simulator will be the primary locus for the training of visual skills that must be developed by the pilot and gunner but that are inappropriate to training in the MT because that device's CGI visual display system has been optimized for other tasks. Terrain flight navigation training will be the principal pilot training activity dependent upon the NSPT's cinematic visual presentation. Emphasis in this training will be upon maintaining geographic orientation and identifying preselected checkpoints by correlating information from tactical maps with observed terrain and cultural features appearing on the visual display.

Effective navigation training in this device will require a library of wide-angle films prepared during actual flights in simulated tactical

environments. In addition to terrain navigation, the NSPT's visual display film library will contain training films that provide tactical scenes in which the gunner can practice target detection and identification skills. Skill in the conduct by the gunner of the frequent verbal interaction that takes place in the aircraft during a terrain flight mission - interaction involving verbal identification of checkpoints and alerts to the pilot concerning upcoming terrain features, obstacles and targets - will be developed in the NSPT, with the instructor simulating the role of the pilot.

SECTION IV

ANALYSIS OF COMPONENTS AND TECHNOLOGY

This section of the study addresses the components that will make up the trainer - the cockpit module, motion system, visual system, computer, and interface - and the principal supporting areas - reliability, maintainability, and integrated logistics support. Current technology is examined; trade-off analyses are conducted; the best technical approaches, it is believed, are selected; and cost effectiveness evaluations, when possible, are made. Conclusions and recommendations, with respect to the various areas studied, are made throughout.

COCKPIT MODULE

Selection of the optimum configuration for the cockpit module must take into account the various modes in which the trainer will be used, constraints imposed by the selected visual system module, and constraints imposed by the instructor/operator module. Various configurations for the cockpit module for the AH-63/64 Flight and Weapons Simulator (FWS) are possible. These include:

1. Separate cockpits for pilot and copilot/gunner.
2. Combined cockpit module to include pilot and copilot/gunner in the actual aircraft arrangement.
3. Combined cockpit module with on-board instructor's station.

The approved training device requirements (TDR) for the AAH-FWS envision that the AAH-FWS will be used in two modes; (1) an integrated mode for simultaneous pilot and gunner training, and (2) independent mode for pilot training in the rear seat and copilot/gunner training in the front seat. For simultaneous training of pilot and gunner the most cost effective arrangement is a combined cockpit module with the pilot and gunner arranged in the actual aircraft configuration.

The major advantage of this arrangement over a separate cockpit arrangement is the reduction of hardware requirements which in turn reduces the overall requirements for maintenance and logistic support. The combined cockpit module requires only a single motion system, one control loading system to activate both the pilot and copilot/gunner flight controls, and one visual display for both the pilot and copilot/gunner. If the pilot and copilot/gunner stations are made separate modules, the motion system, control loading system, and visual systems must be duplicated for each cock-

pit. In addition to the additional equipment required for this arrangement, the design of this equipment and the computer programs that supply the drive signals must insure accurate synchronization between the two cockpit modules. All of this increases the overall cost of equipment, cost of operation, and reduces the reliability of the overall training system.

A combined cockpit module with pilot and copilot/gunner arranged as in the actual aircraft imposes several limitations on the visual system module. Space limitations rule out the use of a single virtual image, infinity optics display system. There are no virtual image displays with exit pupils large enough to accommodate the five foot distances between the pilot's and copilot/gunner's heads. The alternative would be to use a projected image wrap-around screen system. This approach would require a very large screen radius to minimize the perspective distortion for either or both the pilot and copilot/gunner due to their different eye locations.

An alternate approach would be to separate the pilot's and copilot/gunner's stations on a common motion system and provide separate virtual image displays for each station. Present designs of six-post motion systems are capable of accommodating such an arrangement. This arrangement has the advantage of a single motion system, one set of control loading units, and one visual image generator. A single image generator would supply the same visual image signals to both the pilot's and copilot/gunner's display units. This arrangement would sacrifice the physical proximity of the pilot to the copilot/gunner that exists in the actual aircraft. For training value this is not considered a serious disadvantage.

Separate Cockpit Configuration

A severe limitation of the combined cockpit arrangement discussed above is the requirement for both integrated and independent modes of operation. The motion system would preclude simultaneous gunner training in the front seat and pilot transition training in the rear seat. Thus, for independent operation utilization of the AAH-FWS trainer would be limited to one seat at a time.

Separate cockpits, each with its own motion system, flight controls, and visual system would provide maximum flexibility of AAH-FWS trainer utilization. In the integrated mode both seats would be operated in a synchronized mode to provide gunner training for the front seat and pilot training for the rear seat. In the independent mode of operation

the front seat module would provide gunner or copilot flight training while at the same time the rear seat module could be used to provide pilot flight training.

The requirement for flight controls and motion simulation at the front seat would only be required for copilot flight training. When used for independent gunner training the helicopter would be flown by the computer or by the instructor. Also, during independent gunner training there is no need for full motion simulation. An inexpensive one or two degree of freedom limited excursion random motion would be adequate.

Part Task Gunner Trainer

A compromise configuration would consist of a combined front and rear seat cockpit FWS configured to provide integrated pilot and copilot/gunner training and independent flight training for both pilots and copilots. A separate part task trainer configured to provide gunner training would be included to train gunners to detect and recognize targets and use the AAH weapon systems to destroy targets.

This arrangement proves to be the most cost effective in terms of hardware requirements. It has the advantage of a combined cockpit module in that only one motion system and control loading system is required. The cockpit module for the gunner part task trainer would be a simplified reproduction of the AH-63/64 front seat mounted on a two degree of freedom, limited excursion, random motion system. The flight and engine controls would not be activated and all avionic instruments and panels not required for gunner training would be two dimensional photographic facsimilies.

On-Board Instructor Station

From past experience it has been found that an on-board instructor station has many training advantages. It places the instructor in close proximity to the trainees where he can observe the trainee's actions and observe the same instruments and displays that the trainees are using. A secondary advantage is the possible reduction in the number of instructor repeater instruments and visual monitors in cases where the instructor can see the trainee's instruments and visual display.

The arrangement placing the instructor's station on the motion system directly in back of the pilot and copilot proves very successful in the case of transport type aircraft and HH-3 or HH-53 type helicopters

where the pilot and copilot are in a side by side arrangement and there is an excellent view of the instrument panel and controls from the instructor's position. In this arrangement the instructor is essentially in the cockpit.

The arrangement of the AH-63/64 cockpit precludes the arrangement described above. The tandem arrangement of pilot and copilot/gunner with the pilot in back of and two feet above the copilot/gunner would require that an on-board instructor's station be located outside the cockpit canopy. It is concluded that there is no location that would provide an instructor a usable view of both the pilot and copilot/gunner. In addition, any location of the instructor that provided a view of the trainees would interfere with the wide angle visual display.

Recommended Cockpit Module Configuration

It is recommended that the AAH-FWS training system consist of two trainer (cockpit) modules. First, a combined pilot and copilot/gunner cockpit, mounted on a six degree of freedom motion system be provided for integrated pilot/gunner training and individual pilot or copilot flight training. Second, a part task gunner cockpit mounted on a two degree of freedom, limited excursion, random motion system be provided for training gunners to detect, recognize, attack, and destroy hostile targets.

It is recommended that the instructor station for the integrated cockpit be located off the motion system. However, the instructor station for the part task gunnery trainer can be located adjacent to the gunner trainee in such a position that the instructor can view the high resolution visual display.

Cockpit Module Construction

The cockpit module of the AAH-FWS must be a realistic reproduction of the pilot and copilot/gunner stations of the AH-64 helicopter. As a minimum the section of the AH-64 helicopter fuselage between stations 35 and 177 must be represented by the AAH-FWS cockpit. An essential element of the simulated cockpit is that it provides a realistic cockpit environment in which the trainees can be given effective training. To accomplish this the AAH-FWS cockpit must duplicate all AH-64 helicopter instruments, controls, furnishings, equipment, and all other significant items that will be visible to, or operated by the trainees.

The wide angle out-the-window visual simulation requirement for the AAH-FWS requires that greater than normal consideration be given to the external configuration of the trainer cockpit module. In particular the canopy and window portions of the AH-64 helicopter must be duplicated in the AAH-FWS cockpit. Because the fields of view available to the pilot and copilot/gunner are determined by the windshield and window structure it is essential that these structures be duplicated in the AAH-FWS cockpit. In addition, the effects of the window glass in producing reflections of cockpit lighting during night operations are important considerations and must be taken into account in the AAH-FWS.

The external configuration of the AAH-FWS cockpit below the sill line has little or no effect on training. Therefore, for cost considerations the fuselage contours may be approximated with flat surfaces.

Cockpit Structure

In the past, training simulator cockpits have been constructed using various techniques, such as:

1. Molded fiberglass shells.
2. Sections of actual airframes.
3. Aluminum frame and skin structures.

All these techniques, and others, serve the purpose of providing an enclosure for the trainees and provide structural support for panels, controls, and furnishings. Experience, however, has been that fiberglass shells or actual airframe structures do not allow installation of adequate access provisions for maintenance. In the case of the AH-64, where the equipment in both cockpits is very compact, provision must be made for access through the cockpit shell for maintenance.

The preferred techniques for providing adequate access for maintenance would be to design and construct the cockpit using a structural aluminum frame with removable skin panels attached with quarter-turn fasteners. This will provide ready access for maintenance of equipment in the side consoles and front and rear sections of the cockpit module. The cockpit frame should include a rigid base structure, able to support without deflection the flight controls and their push-pull rods. The structure should form the cockpit sides up to the canopy sill line, include bulkhead structures to support the instrument panels, and provide supports for the pilot and copilot/gunner seats.

As discussed above, the canopy and windows must duplicate the appearance and optical function of the actual airframe components. The best method for accomplishing this would be to use actual airframe components.

Ingress and Egress

Ingress and egress to the AH-64 helicopter cockpit is through the two canopy door panels on the right side. The configuration of the seats and side consoles in the AH-64 helicopter cockpits precludes any method of ingress and egress except over the cockpit sill. Thus, since it is recommended that the canopy above the sill be actual or reproduced airframe components, ingress and egress can best be provided by using the two canopy door panels on the right side. This would provide ingress and egress the same as it is in the actual AH-64 helicopter.

Mounting

An aluminum alloy cockpit base frame weldment should be provided to serve (1) mounting the cockpit shell structure, (2) as the floor in the pilot and copilot/gunner stations, (3) mounting of the flight controls and linkages, (4) mounting for the consoles, seats, and other interior aircraft furnishings, and (5) interface the cockpit module to the motion system module. The lower surface of the cockpit base frame should be provided with structural attachment members to allow bolting to the cockpit motion system platform structure. It is essential that the cockpit base frame have sufficient strength and rigidity to transmit all acceleration and vibration forces from the motion system platform to the cockpit components.

Recommendations

It is recommended that the AAH-FWS cockpit module consist of an aluminum frame, aluminum skin reproduction of the AH-64 helicopter fuselage section between stations 35 and 177 supported on a welded aluminum structural base frame. All the aluminum skins should be removable, secured by quarter turn fasteners, to allow maximum access through the cockpit exterior for maintenance.

The recommended construction of the canopy and windows above the sill line consists of using actual airframe components or reproductions of these components. Ingress and egress would then be provided through the two right side door panels the same as in the actual aircraft.

Flight and Engine Controls

The AH-64 helicopter primary flight control system is an irreversible dual-boosted hydraulic system which positions the main and tail rotor blade pitch in response to pilot control movements. The cockpit controls consist of cyclic stick, collective stick, and directional pedals. The pilot's set of controls are mechanically connected to the copilot's controls and to the primary flight control actuators through a system of push-pull rods and bellcranks. Since the hydraulic boost system is irreversible, preventing any feedback of aerodynamic forces to the controls, artificial feel and trim control are provided by bungee springs in parallel with each control channel. Trim adjustment is provided by the pilot adjusting the neutral position of the bungee spring.

In addition to manual flight control there is a three-channel, (roll, pitch, and yaw) automatic stabilization equipment (ASE) system in series with the pilot's controls. This system provides an electrohydraulic input to the flight controls that has a maximum authority of 10 percent of manual authority to provide stability augmentation. In addition the ASE provides an electrical back-up flight control system that can be used by either the pilot or the copilot to control the helicopter in case of damage to the mechanical control system. When activated, this system disconnects the mechanical control input to the flight control actuators and provides electrohydraulic control from electrical transducers attached to the flight controls.

The primary flight control hydraulic actuators are powered by two separate hydraulic systems (flight control hydraulic system and utility hydraulic system) in tandem arrangement. Either system alone can provide full flight control. However, if both hydraulic systems are failed, controlled flight is not possible. To cope with this emergency each flight control channel has a hydraulic accumulator that stores sufficient hydraulic power to make a safe landing following a complete hydraulic power failure.

Engine Controls

In the AH-64 helicopter the turbine engines are controlled by power lever quadrants located on the left console of both the pilot and copilot/gunner stations. The two quadrants are mechanically connected together and to the engine fuel controllers. Thus the engines can be controlled

by either the pilot or copilot.

Extent of Simulation

A significant requirement of the AAH-FWS includes training of AH-64 pilots to transition into the AH-64 helicopter and standardization/proficiency training in the AH-64 helicopter. To provide efficient training in these areas the AAH-FWS must include fully activated flight and engine controls to include:

1. Pilot and copilot cyclic sticks.
2. Pilot and copilot collective sticks.
3. Pilot and copilot directional pedals.
4. Pilot and copilot engine control quadrant.
5. ASE controls.
6. Trim controls.
7. Back up control system.
8. Wheel brakes.
9. Rotor brake control.

Accurate force-feel characteristics of all the pilot/copilot operated controls must be reproduced for all modes of operation throughout the full operating envelope of the AH-64 helicopter. All pilot/copilot controlled adjustment controls such as friction locks and pedal position adjustments must operate the same as they do in the operational aircraft.

In addition to accurate simulation of all normal operation, the above controls must be made to feel and respond correctly to all anticipated system failures and combat damage such as:

1. Loss of flight control hydraulics.
2. Loss of utility hydraulics.
3. Loss of both hydraulic systems.
4. Trim failures in each channel.
5. ASE failures in each channel.
6. Severed control rod in each channel.
7. Engine hot start, flame out, etc.
8. Fuel system failures.
9. Fuel controller failures.
10. Engine oil failures.

For all failures, simulation of all related and dependent aircraft systems and the aerodynamic performance of the helicopter must be provided.

To provide efficient standardization and proficiency training the flight control systems must include provisions for recording and playing back segments of a mission. Playback should be provided for recording the performance of a trainee for later playback for critique. Also it must be possible to record demonstration missions to be played back for trainee instruction.

Techniques are readily available to activate and provide accurate simulated force-feel loading to all the AH-64 helicopter flight and engine controls. A system of loading units using electrohydraulic force actuators in combination with bungee springs reproducing the artificial fuel springs have been successfully used to simulate helicopter flight controls.

Recommendations

An economical approach to the design of the flight and engine controls for the AAH-FWS is recommended as follows. It is recommended that actual airframe control systems (collective, cyclic, directional pedals, and engine quadrants) be installed in the pilot and copilot/gunner stations of the cockpit. Airframe components should be installed between these controls and the space back of the pilot's seat. Electrohydraulic/bungee spring loading units can then be installed back of the pilot's seat to provide loading forces to each control. This arrangement would provide optimum maintenance accessability.

All flight, engine, and secondary controls must be fully activated to provide accurately simulated force-feel characteristics. All related helicopter systems and aerodynamic performance must respond correctly to all pilot control inputs and instructor inserted failures.

The control loading systems for the primary flight controls must include provision for recording all pilot control actions. The systems must then be able, under instructor control, to play back these control actions.

Cockpit Module Environment

Heating and cooling air to maintain comfort conditions in the pilot and copilot/gunner stations in the AH-64 helicopter are provided by an air cycle environmental control unit. This unit normally uses compressed air from the shaft driven air compressor or, in case of failure of this air supply, from the engine bleed air system. Cockpit temperature is controlled by an adjustable thermostat at the pilot's station.

Extent of Simulation

The results of a study of the AH-64 helicopter environmental system and the pilot's tasks show that simulation of the environmental control system should be limited to activation of the caution and warning lights and controls associated with the ice detection and de-icing systems. Simulation of the airconditioning and defogging systems is not required. However, provision should be made to maintain comfortable conditions in the cockpit since these spaces will be completely enclosed by the cockpit shell and canopy.

The AAH-FWS will be installed in an airconditioned building; therefore, there is no need to provide heating to the cockpit spaces. The only requirement should be for a supply of ventilation air and cooling air.

Aural Simulation

For realistic training, the AAH-FWS cockpit module should present to the pilot and copilot/gunner the same sound environment that they would experience in the AH-64 helicopter. Thus an aural simulation system must be provided to reproduce the following sounds:

1. Engine sounds.
2. Gear box sounds.
3. Rotor and fuselage sounds.
4. Sounds from auxiliary systems.
5. Sounds from weapon operation.

Recommendations

It is recommended that the AAH-FWS include an air conditioning unit designed to deliver a constant supply of filtered ventilzation air to both the pilot's and copilot/gunner's space. This air conditioner should be external to the cockpit module and should be designed to cool the ventilation air supply sufficiently to maintain a temperature of 55°F in the cockpit with an ambient air temperature ranging between 70°F and 110°F. Control of the temperature in the cockpit should be by means of a thermostat set by the pilot's temperature control.

It is also recommended that the AAH-FWS cockpit module include an aural simulation system that will accurately synthesize all engine, gear box, rotor, auxiliary system, and weapon release sounds. The simulation must be realistic for all operational modes, and throughout the performance range of the AH-64 helicopter.

MOTION SYSTEM MODULE

Aircraft Operational Motions

The aircraft motions to be simulated include those due to taxiing, in-flight maneuvering, atmospheric turbulence, weapons release and firing, powerplant, rotor and equipment operation, and aerodynamic buffet.

These motions may be grouped into two broad categories; (1) low-frequency motions due to taxiing, in-flight maneuvering, and turbulence, and (2) high-frequency motions and jolts due to weapons release and firing, powerplant, rotor and equipment operation, and aerodynamic buffet.

The low-frequency motions of the first category are motions involving accelerations up to approximately 3.0 g's and frequencies up to approximately 2.0 Hz which are associated with the vast majority of routine flight in a tactical attack helicopter. Table III of AMC-SS-AAH-H10000A, which is included in this report as Table 1, indicates that approximately 82% of the total YAH-64 maneuver spectrum is composed of maneuvers involving peak $N_{Z_{C.G.}}$'s between 0.75 and 1.25, and that approximately 92% of the maneuver spectrum is composed of maneuvers involving peak $N_{Z_{C.G.}}$'s between 0.50 and 1.50. These are the motions associated with the basic helicopter flying qualities and aerodynamic response, therefore it is essential that these basic motions be simulated in the AAH Full-Mission trainer.

The high-frequency motions and jolts of the second category involve impulsive accelerations and disturbance frequencies of approximately 2.0 Hz and higher. It is important that these motions be simulated in both the AAH Full-Mission Trainer and the separate CPG Trainer.

Motion System Requirements

The general requirements for motion simulation, as related to training effectiveness, are developed and discussed in Section II of this study report. The extent of motion simulation, ie, the number of degrees of freedom of motion, required for effective training, however, can not be determined through a consensus of the literature surveyed in that section. Therefore, in order to arrive at a recommendation for this requirement, Sperry SECOR surveyed helicopter-trainer user personnel at the Fort Rucker and Fort Knox helicopter training centers. Without exception, all instructors and pilots surveyed indicated a strong preference for six degrees of

Table 1

YAH-64 Maneuver Spectrum

Peak Nz at c.g.	Time at g (sec)	Cumulative Exceedances per 4500 hrs.
3.00	0.8	200
2.75	1.2	500
2.50	1.7	1,000
2.25	2.8	2,000
2.00	4.0	5,000
1.75	6.0	10,000
1.50	10.0	20,000
1.25	12.0	150,000
0.75	4.2	60,000
0.50	2.8	8,000
0.25	2.5	1,000
0	2.0	200

Reference:
AMC-SS-AAH-H10000A
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freedom of motion simulation in helicopter trainers. This preference among the trainer user personnel is deemed sufficient to justify a recommendation for six degrees of freedom of motion, particularly in view of the lack of any clear consensus on the subject in the technical literature.

Due to the constraints imposed by the visual-system-related requirement to maintain the trainee station excursions within a relatively small space about the projection screen focal point, the motion excursion requirements for the AAH Full-Mission Trainer are well within the limits of capability of standard state-of-the-art motion systems. The objective, then, is to determine the most cost-effective approach for generating the required six degrees of freedom of motion simulation.

One approach for providing six degrees of freedom motion is the utilization of a cascaded motion system. This approach was investigated utilizing Sperry SECOR's three-degree-of-freedom cascade motion system, which is described in Figures 3, 4 and 5, as a starting point and estimating the additional cost involved in modifying the system to provide six degrees of freedom, increased vertical excursion capability, and a payload capability of 6000 pounds. This investigation revealed that the overall development, hardware and labor costs for this approach would roughly equal the cost of developing or procuring a standard six-degree-of-freedom synergistic motion system.

Based on these results, it is concluded that a standard six-degree-of-freedom synergistic motion system would provide the most cost-effective alternate for meeting the desired motion simulation requirements established for the AAH Full-Mission Trainer. This type of motion system also provides increased cost effectiveness due to the standardization of actuators, servovalves and other components; thereby reducing provisioning and maintenance requirements.

It is estimated that the weight of the AAH Full-Mission Trainer cockpit would be approximately 3000 pounds, and that an on-board instructor's

Figure 3

SPERRY SECOR THREE-DEGREE-OF-FREEDOM MOTION SYSTEM

The Sperry SECOR motion system is a standard three-degree-of-freedom system that provides motion in roll, pitch, and heave. This motion system was produced and delivered as a part of two A-4M flight trainers, two A-4H flight trainers, two A-4N flight trainers, and one A-4KU flight trainer. These systems have proven very effective in providing cues of acceleration and attitude changes in vertical translation, pitch attitude and roll attitude. Due to superior response characteristics, the Sperry SECOR three-degree-of-freedom system is particularly effective in providing motion simulation for high performance attack and fighter type flight simulators.

Each of the three motions are independent of the others. Thus, the amplitude of one degree of freedom is not limited by the instantaneous position of the other degrees of freedom. Also, since the computation of the motion of one actuator is independent of the other two, the motion system program module is very short and does not have the complexity of a program for a synergistic system where every motion requires the calculation of an input to all six actuators.

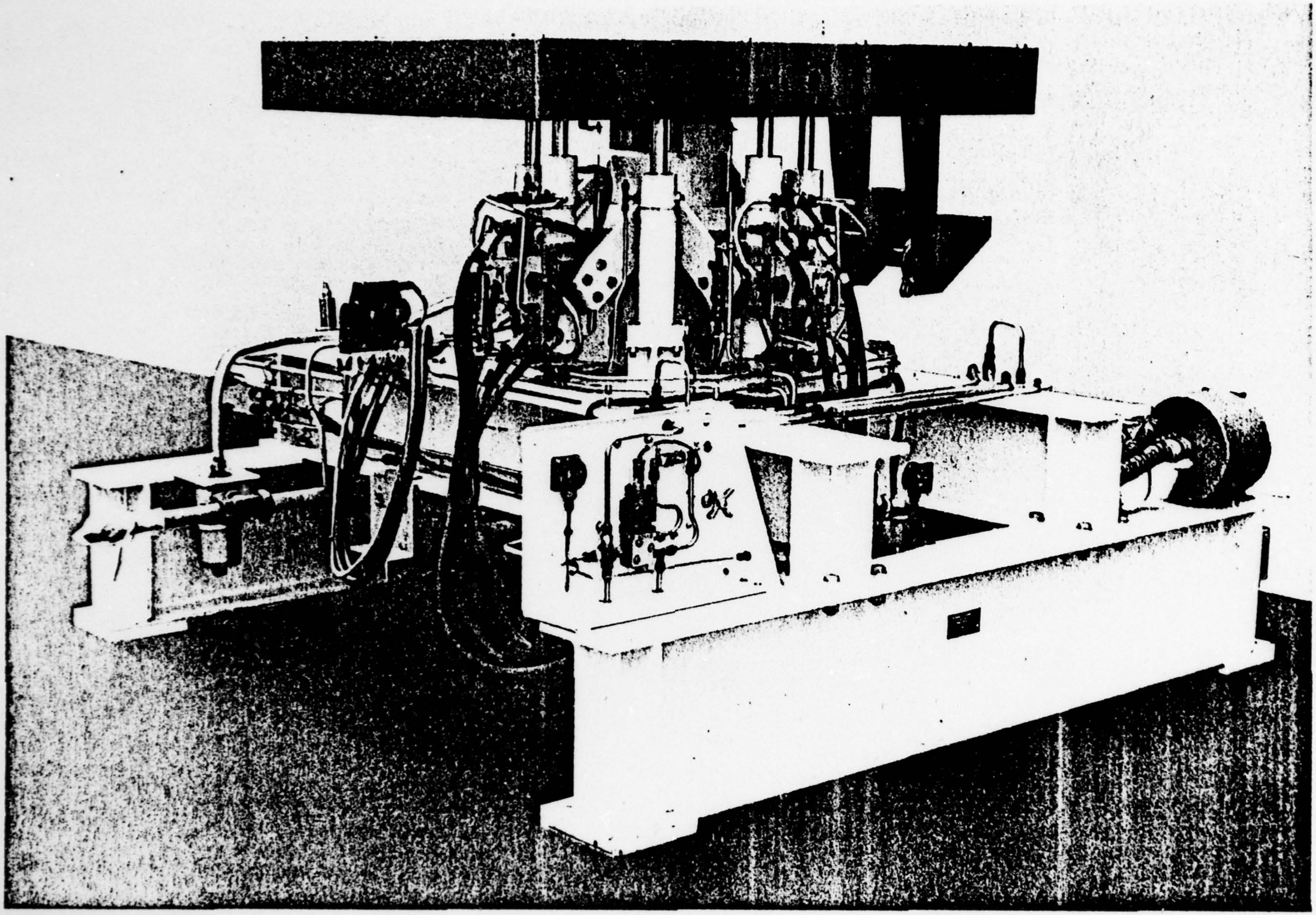
Another feature of the Sperry SECOR three-degree-of-freedom motion system design is that all hydraulic actuators are close coupled with very small trapped hydraulic fluid volume. Thus, the response time is low, thereby providing excellent frequency response and accurate coordination with the trainer G-suit and visual system.

The Sperry SECOR motion system is an electro-hydraulically actuated servomechanism which provides the following displacements, velocities, and accelerations:

Motion	Max. Excursion	Max. Velocity	Max. Acceleration
Heave	$\pm$6 Inches	$\pm$20 In/Sec	$\pm$.9 G
Roll	$\pm$15 Degrees	$\pm$30 Deg/Sec	$\pm$50 Deg/Sec^2
Pitch	$\pm$15 Degrees	$\pm$30 Deg/Sec	$\pm$50 Deg/Sec^2

The motion system meets the time response and frequency response requirements of MIL-STD-1558.

The design payload capability of the Sperry SECOR three degree of freedom motion system is 2000 pounds. The payload capability may be increased to 3400 pounds through the incorporation of minor modifications which have been identified in a preliminary engineering analysis.



Sperry Secor Three DOF Motion System

Figure 4

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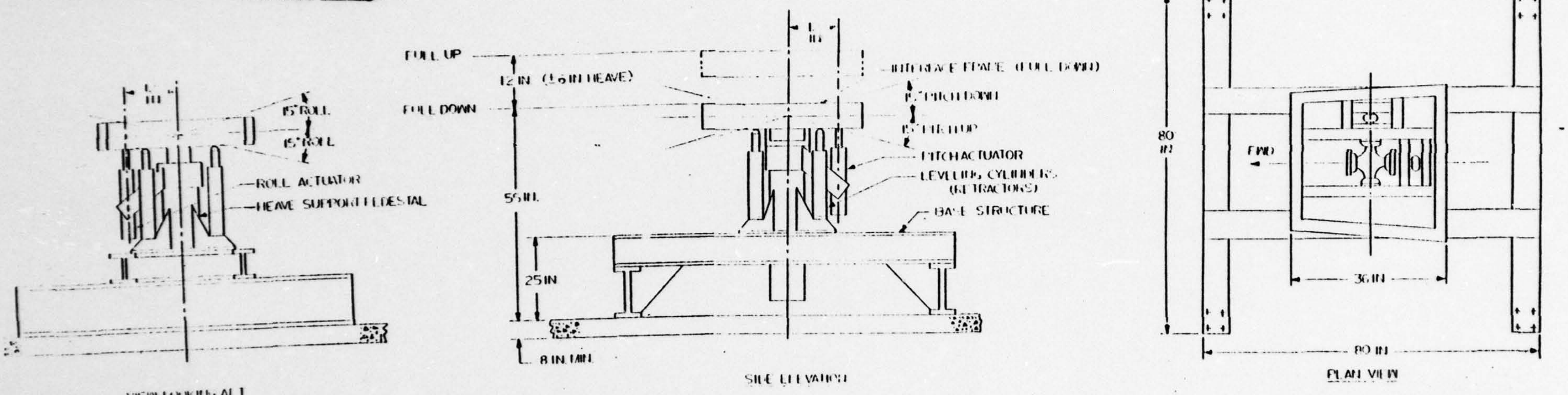

SPERRY SECOR
THREE DEGREE-OF-FREEDOM
MOTION SYSTEM

Figure 5

station would add another 2000 pounds as a worst case. Thus, the total payload requirement for the motion system will be approximately 5000 pounds, which is well within the capability of state-of-the-art synergistic motion systems.

Sperry SECOR's approach for satisfying the AAH Trainer motion system requirements developed in this section would be to design and develop a six-post six-degree-of-freedom synergistic motion system as described below.

Motion System Description

The Sperry SECOR motion system is a standard six-leg six-degree-of-freedom synergistic system which provides motion consisting of pitch, roll, yaw, heave, lateral, and longitudinal components. The physical movement of the motion system is determined by computations based upon six degrees of aircraft freedom. The simulated motions optimize the tracking of the total acceleration vector of the simulated aircraft including changes in magnitude and direction. The motion system follows the aircraft dynamic motion subject to an attenuation function and a washout function which is below the threshold of perception of the training crew members. The motion system is controlled so as to respond to aircraft center-of-gravity movement, center-of-pressure movement, fuel depletion, internal and external cargo loading, variable aerodynamic effects, and progressive malfunctions. The motion system is also controlled such that the cockpit will maintain a relative pitch attitude corresponding to the steady-state simulated aircraft pitch attitude. The motion system is designed to operate with minimal hunting and with no snubbing against cushion stops during normal operation.

The motion system servoactuators will be manufactured to Sperry SECOR specifications. The actuator stroke will be 60 inches, which will provide $\pm$ 30 inches of actuator travel about the neutral position. The piston diameter will be 3.50 inches and the rod diameter will be 2.50 inches. This will provide a ram having a two-to-one ratio between the head-end effective piston area and the rod-end effective piston area. The areas thus will be 9.621 sq. in. for the head end and 4.908 sq. in. for the rod end. System pressure will be maintained at a value that will produce an actuator rod buckling factor-of-safety of approximately 10. Dual 252.25 series MOOG/MTS servovalves will be used to control hydraulic fluid flow to each actuator. LVDT position transducers, tachometers, and ΔP trans-

ducers will furnish feedback signals for the servovalve control loops.

The motion platform, to which the payload will be attached, will be supported by six identical servoactuators arranged in three bipod pairs. The actuators will be connected to the motion platform and the motion base assemblies by pin-and-clevis joints.

Figure 6 shows the general arrangement of the motion system. Major dimensions are included.

Figures 7 through 11 show the maximum excursions of the motion system in each degree of freedom.

Payload

The motion system payload will be 15,000 pounds.

All load-carrying structural members will be sized to provide a minimum safety factor of four times yield strength under simultaneous conditions of worst-case configuration and worst-case dynamic loads associated with the 15,000 pound payload. A proof load test will be performed to verify the structural integrity of the motion system.

Excursions, Velocities and Accelerations

The motion system excursion, velocity, and acceleration capabilities in each degree of freedom will be as follows:

		Max. Capability	Reduced for AAHT
Pitch	Excursion	+30° -25°	±15°
	Velocity	±20°/SEC	
	Acceleration	±100°/SEC^2	
	Acceleration Onset	±300°/SEC^2/SEC	
Roll	Excursion	±27°	±15°
	Velocity	±23°/SEC	
	Acceleration	±100°/SEC	
	Acceleration Onset	±300°/SEC^2/SEC	
Yaw	Excursion	±32°	No reduction
	Velocity	±24°/SEC	
	Acceleration	±100°/SEC^2	
	Acceleration Onset	±300°/SEC^2/SEC	

Vertical	Excursion	±36 IN.	±12 IN.
	Velocity	±29 IN./SEC	
	Acceleration	±.8 g	
	Acceleration Onset	±5 g/SEC	
Lateral	Excursion	±42 IN.	±12 IN.
	Velocity	±34 IN./SEC	
	Acceleration	±.7 g	
	Acceleration Onset	±3 g/SEC	
Longitudinal	Excursion	+51 IN. -42 IN.	±12 IN.
	Velocity	±33 In./SEC	
	Acceleration	±.7 g	
	Acceleration Onset	±3 g/SEC	

Motion System Safety Provisions

The motion system will be provided with an emergency cut-off control that can be operated from the inside or the outside of the flight compartment. A master maintenance control will be provided to ensure that the motion system can be deactivated when maintenance personnel are inside the motion structure. The motion safety system will consist of hydraulic, mechanical and electronic subsystems each capable of operating irrespective of the status of the other.

The hydraulic safety system will include the following features:

- Fail-safe geometry to prevent an unsafe condition under any combination of actuator travels.
- Progressively smooth throttling of oil flows as limits of motion are approached. The energy-absorption capacity will be adequate to handle a runaway-actuator condition.
- Hydraulic cushions at travel limits.
- When the system is shut down, a control will be provided to dump system pressure to zero within one minute.
- Automatic easy-down in case of total hydraulic failure.

An electronic failure-detection system will be supplied which will detect system malfunctions and cause the motion system to return to the rest position. The conditions which will be detected by the electronic safety system are as follows:

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AH-64 FLIGHT AND WEAPONS SIMULATOR CONCEPT FORMULATION STUDY.(U)

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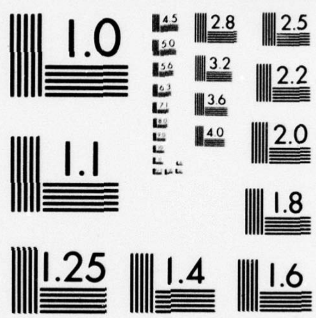

MICROCOPY RESOLUTION TEST CHART
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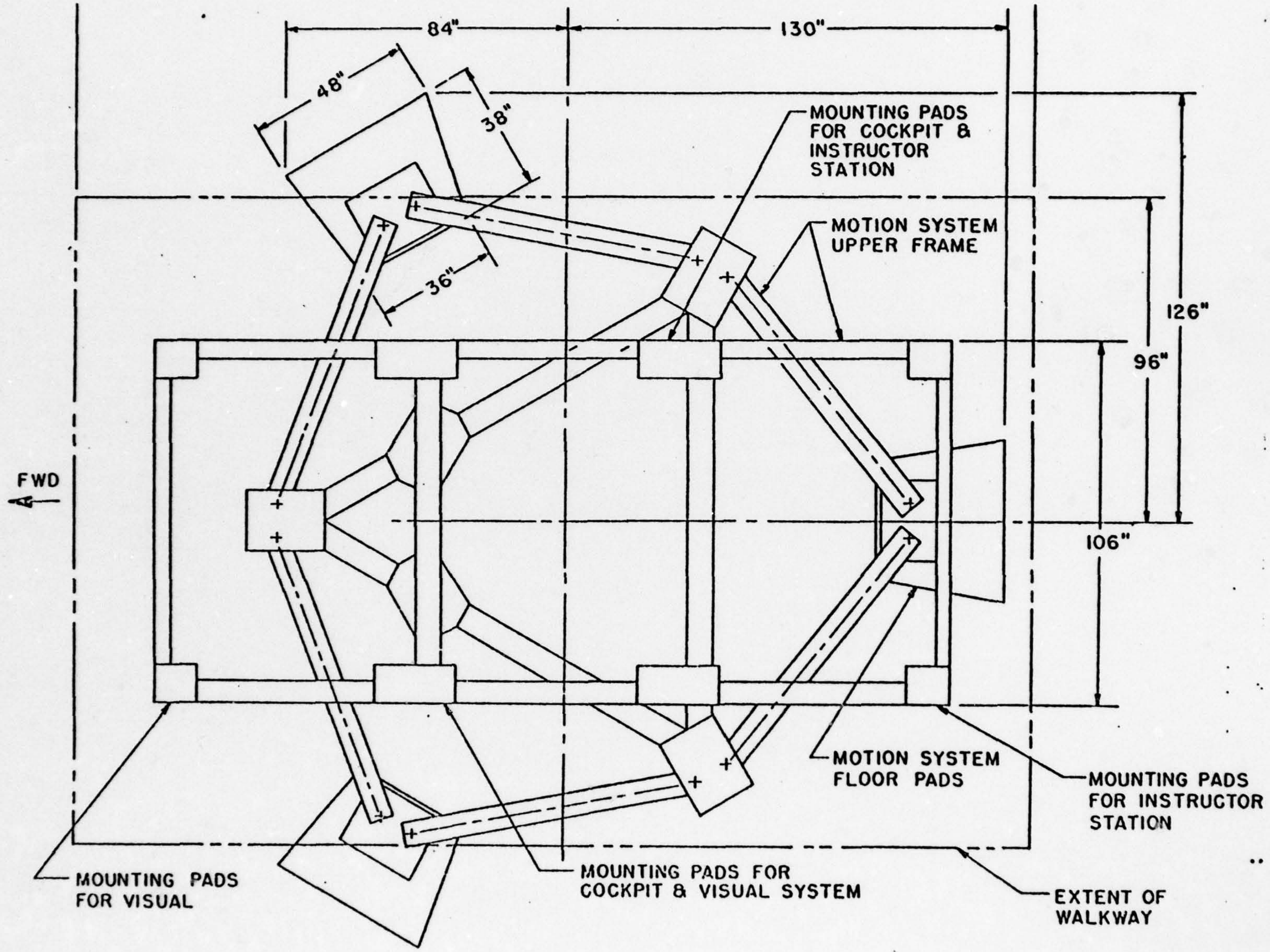
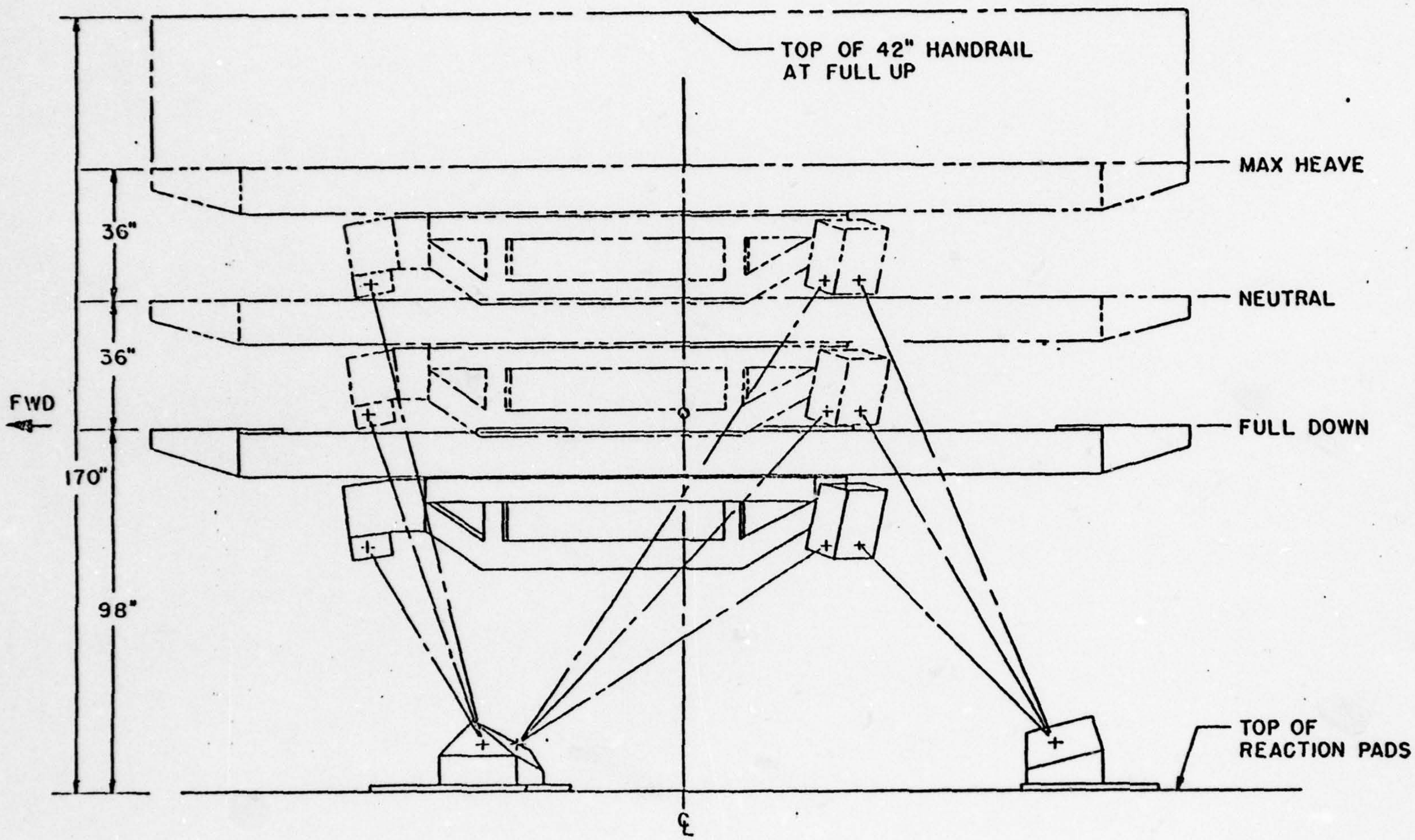


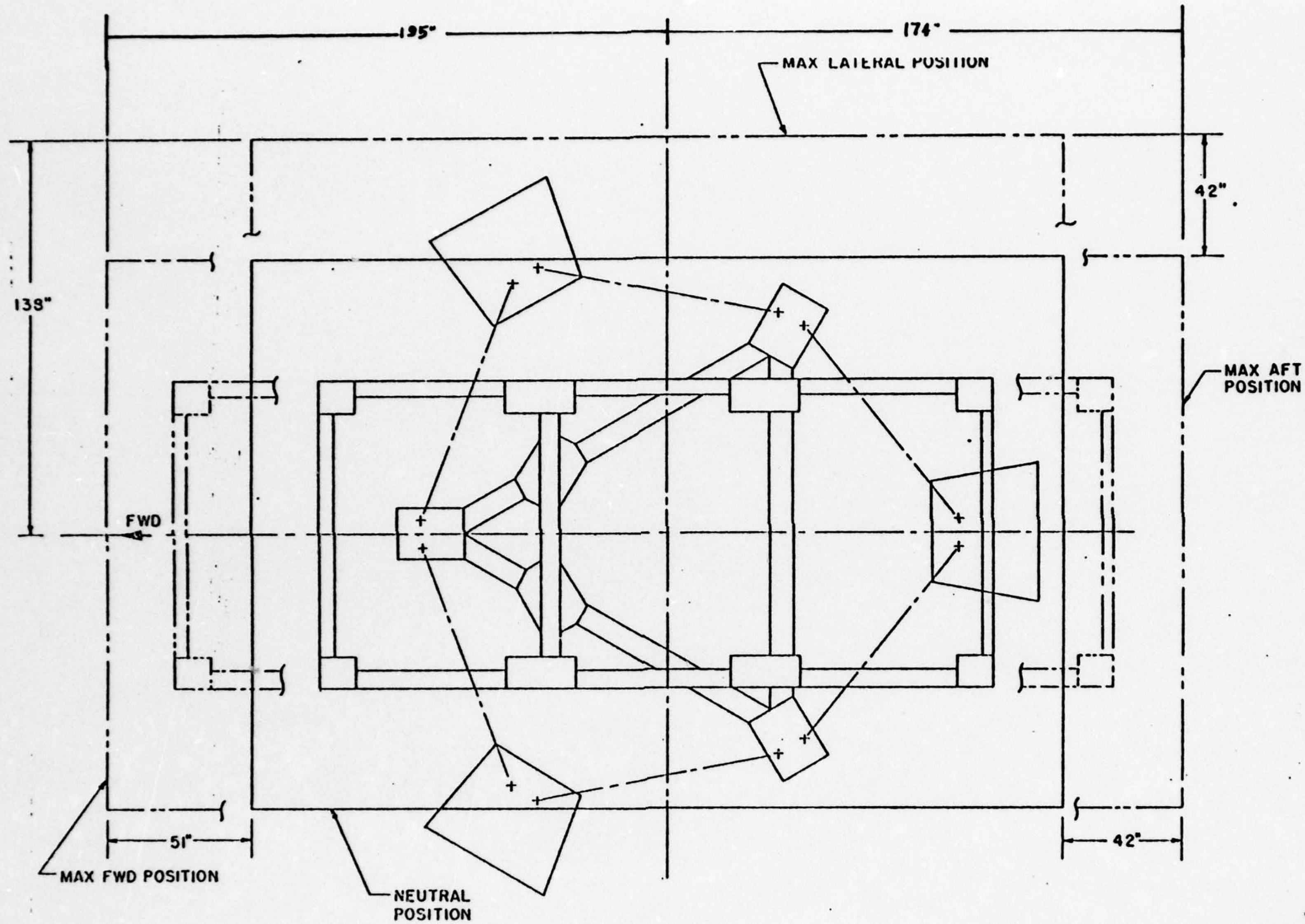
MOTION SYSTEM GENERAL ARRANGEMENT

Figure 6



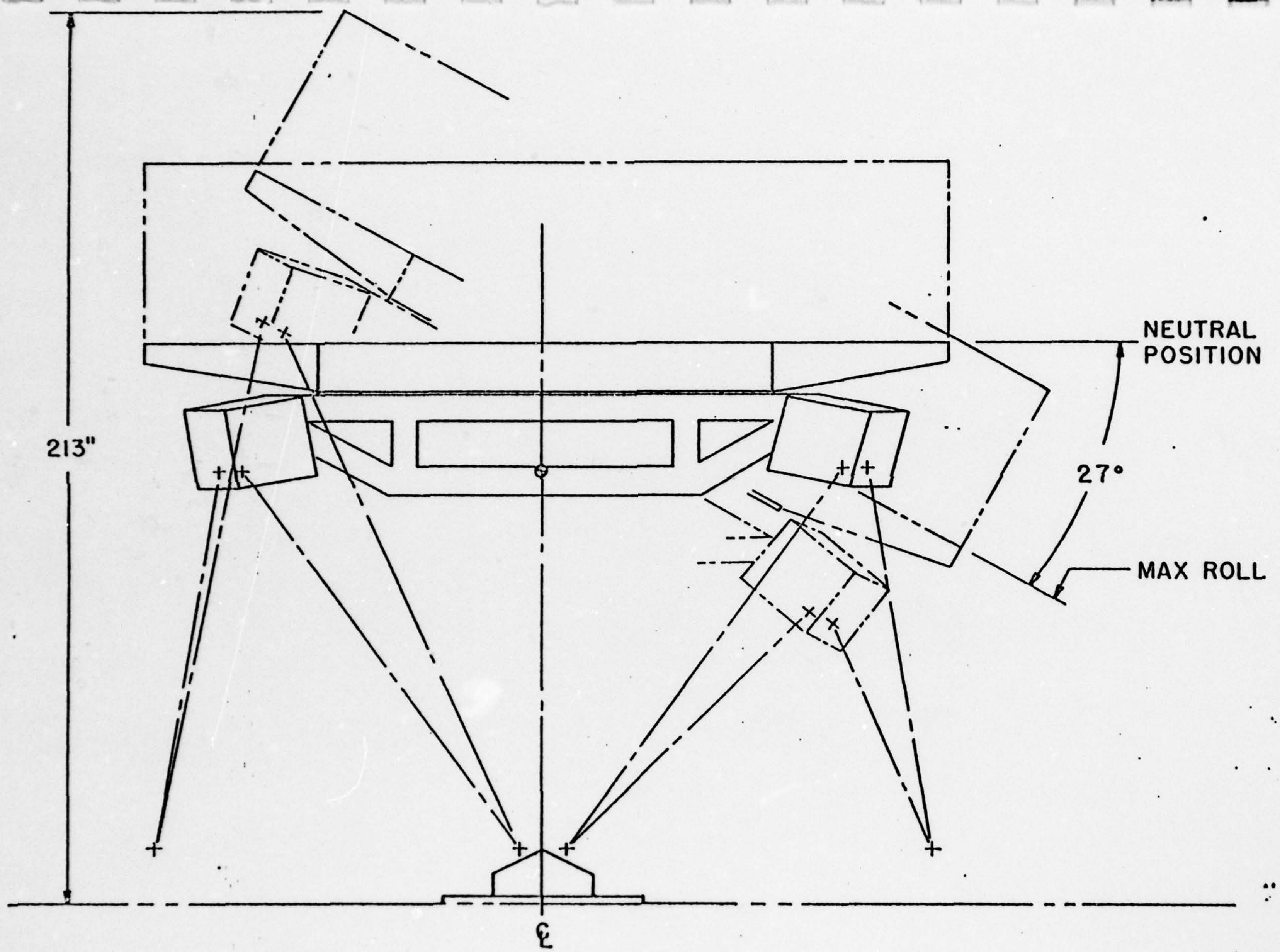
MOTION SYSTEM HEAVE LIMITS

Figure 7



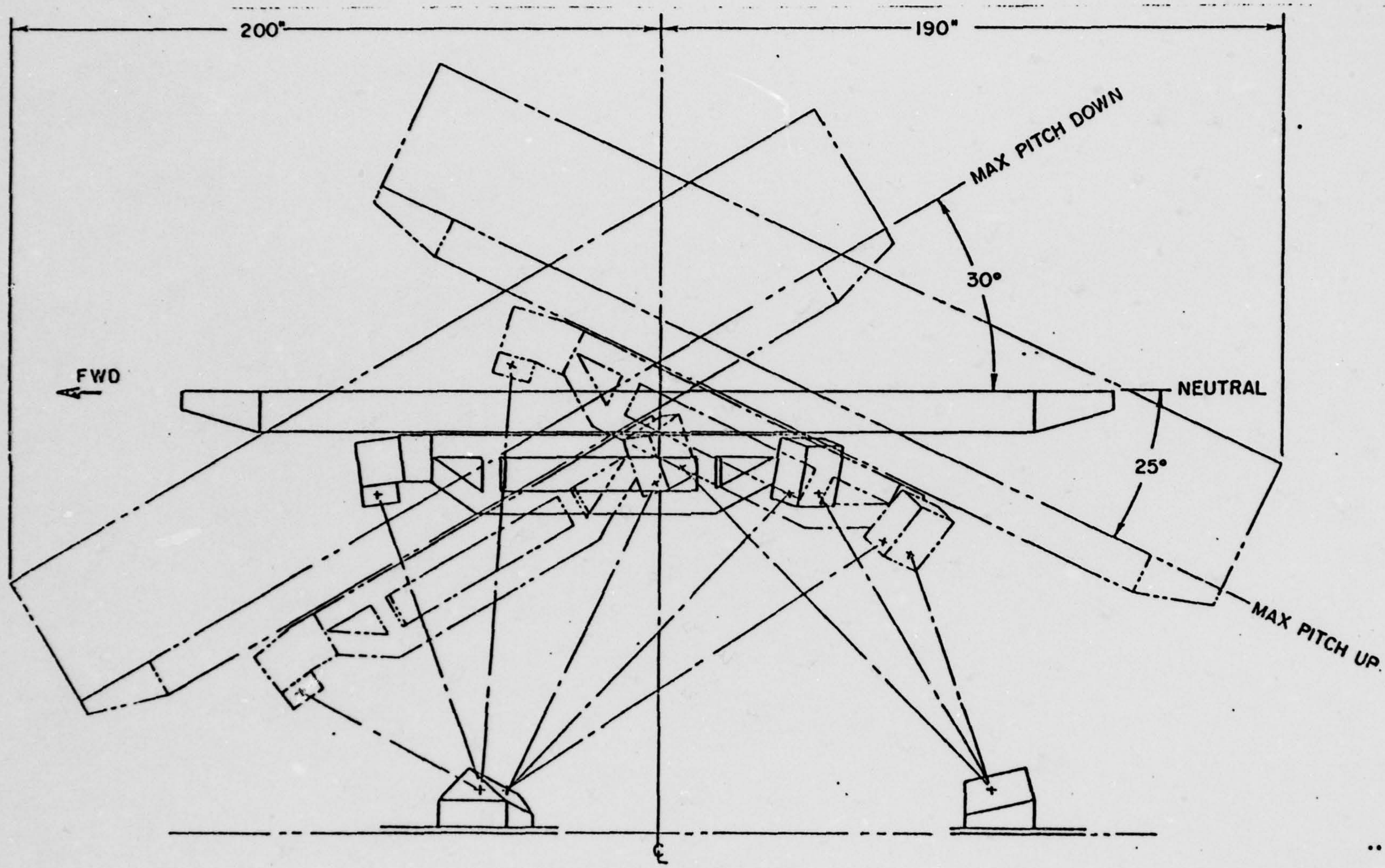
MOTION SYSTEM
LATERAL AND LONGITUDINAL LIMITS

Figure 8

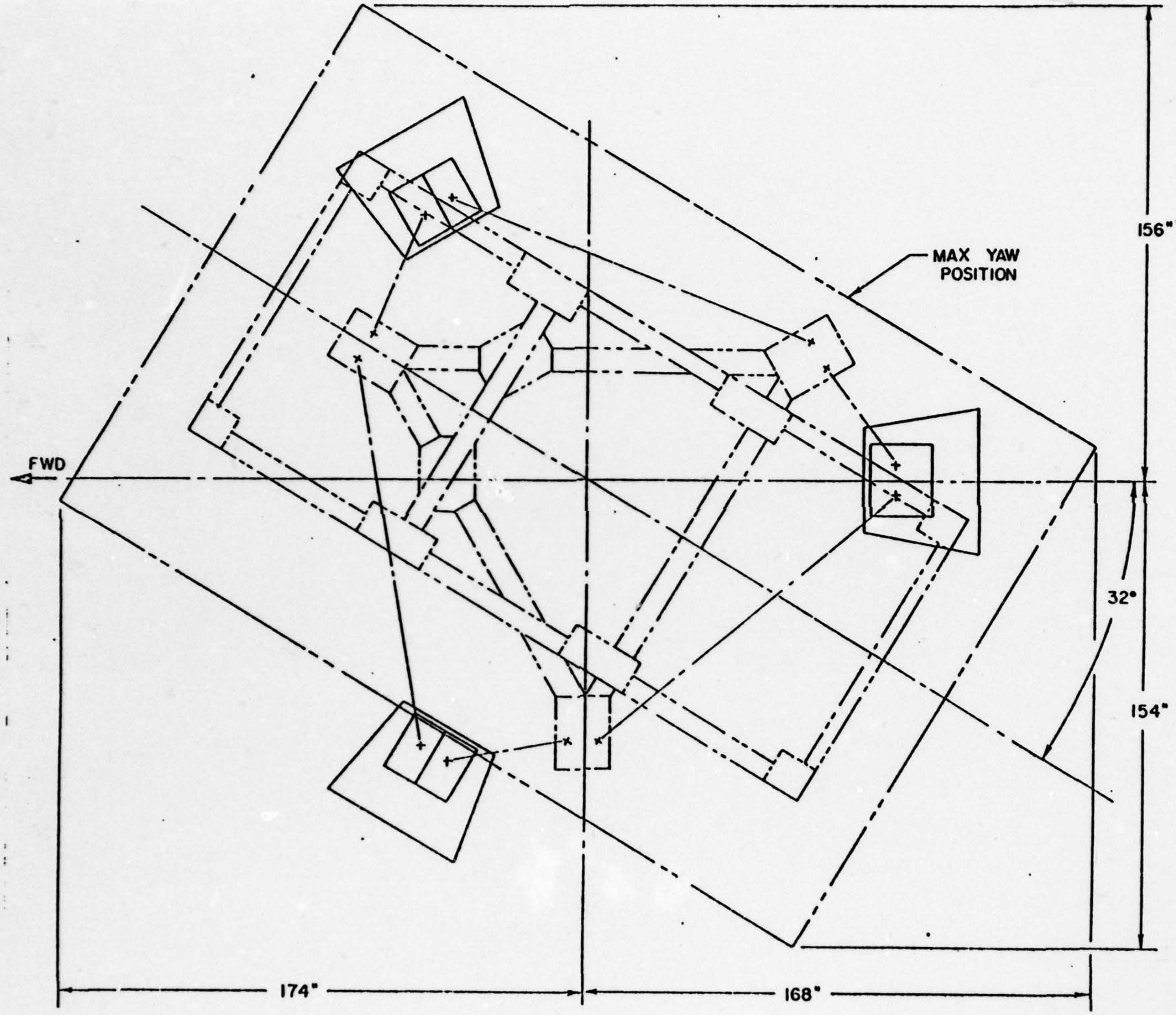


MOTION SYSTEM ROLL LIMITS

Figure 9



MOTION SYSTEM PITCH LIMITS
Figure 10



MOTION SYSTEM YAW LIMITS
Figure 11

- Travel limits exceeded. (Each hydraulic actuator will be provided with an electrical limit switch at each end. Activation of any one limit switch will cause the motion system to shut down.)

- Provision for program not iterating (checks discrete output changing state at the nominal computer iteration rate.)

- Excessive signal to servo valves, caused by amplifier failure.

- Provision for discrepancy in the digital-to-analog or analog-to-digital signal conversion.

- Operation of any EMER OFF switch.

- Low Oil Pressure - loss of system operating pressure.

- Loss of Electrical Power - loss of any voltage, including loss of power to the failure detection system, will cause the enabling valve to open. This will cause the motion platform to return to the rest position at a controlled rate.

It will not be possible to engage the motion system unless all interlocks are in a safe position. Operation of the instructor's switch when the interlocks are in an unsafe position will not cause the motion to go on even if the interlocks subsequently move to the safe position.

When any EMER-OFF switch has been activated, the motion system will remain inopenable until the instructor initiates the normal control switch starting sequence, or until a reset is manually performed on the Maintenance Panel.

Indicator lights will be provided for the following:

- Manual Shut-Off - indicates that the motion system was shutoff by one of the EMER OFF switches.

- Out of Limits - indicates that an actuator has exceeded its travel limits and has activated a limit switch.

- Loss of Power - indicates loss of power to the motion system (light will not illuminate if power for light is lost, until power is restored).

- Low Oil Pressure - indicates the motion system pressure has dropped below a predetermined value.

- High Oil Temperature - indicates that the oil temperature has exceeded a certain predetermined value.

- Filter Pressure Differential - each of ten lights will indicate a contaminated filter. The lights will sense one filter on in-

put to each jack, one in the cooling line, one in the case drain line, one in the system return line, and one in control force system.

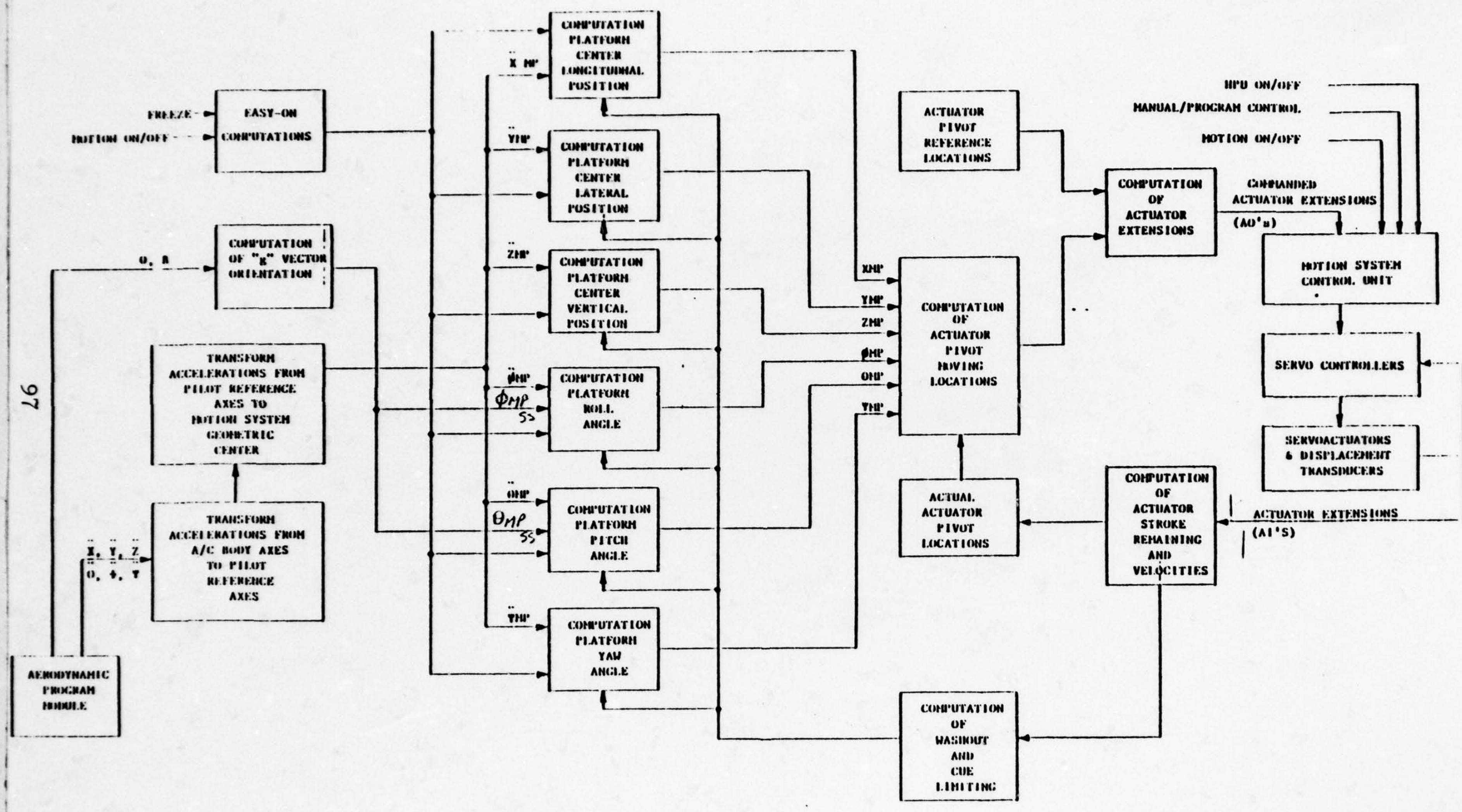
- Fail-safe electrical interlocks will be provided to prevent activation of the motion system in an unsafe condition.

Aircraft-to-Motion-System Drive Equations

Motion system drive equations will generate the control signals required to simulate realistic aircraft accelerations, attitudes, and buffet motions in six degrees of freedom. The inputs will be the aerodynamic program module and the current position of the motion platform. The motion system program module will compute the desired accelerations and "g" vector orientation in six degrees of freedom with respect to the center of gravity and body axis of the aircraft. A coordinate transformation will then be made to compute the corresponding desired accelerations and "g" vector orientation at the geometric center of the motion system moving platform. Using this data, the motion system program module will then compute a new desired extension for each of the six actuators. At the same time it will apply washout criteria, actuator velocity and limiting criteria, and platform easy-on criteria to compute the final actuator extension analog output to each servo valve amplifier.

Figure 12 is a block diagram of the motion system drive equations. Symbols are defined as follows:

$\ddot{X}$	Total Longitudinal Acceleration
$\ddot{Y}$	Total Lateral Acceleration
$\ddot{Z}$	Total Vertical Acceleration
$\ddot{\phi}$	Roll Acceleration
$\ddot{\theta}$	Pitch Acceleration
$\ddot{\Psi}$	Yaw Acceleration
θ	Pitch Angle
$\ddot{X}_{MP}$	Platform Longitudinal Acceleration
$\ddot{Y}_{MP}$	Platfrom Lateral Acceleration
$\ddot{Z}_{MP}$	Platform Vertical Acceleration
$\ddot{\phi}_{MP}$	Platform Roll Acceleration
$\ddot{\theta}_{MP}$	Platform Pitch Acceleration



BLOCK DIAGRAM

MOTION SYSTEM DRIVE PROGRAM AND CONTROL SYSTEM

Figure 12

$\ddot{\Psi}_{MP}$ Platform Yaw Acceleration

θ_{MP} Platform Pitch Attitude

As shown, the inputs to the motion system program module will be aircraft accelerations in six degrees of freedom, aircraft pitch attitude, sideslip angle, freeze, and ON/OFF control. The program will first accept the six acceleration terms referenced to the aircraft center of gravity and body axis system and translate them to the pilot's reference location. These terms will then be translated from the pilot's reference location to an axis system fixed to the geometric center of the motion system upper frame.

Steady-state pitch attitude and sideslip angle from the aerodynamic program module will be used as the input to a computation of the "g" vector orientation. The output terms $\theta_{MP_{SS}}$ and $\phi_{MP_{SS}}$ will represent motion system upper platform pitch and roll angles in the steady-state, or initial, condition.

Using as inputs platform accelerations, platform pitch and roll attitudes, washout and cue-limiting terms, and an easy-on term, the program will compute commanded motion system platform positions in the six degrees of freedom. A freeze command input will have priority control over this computation to return the platform to neutral position at slow rate. Motion ON or OFF command inputs will only be possible in the freeze mode. If these inputs are initiated when the trainer is out of freeze the trainer will revert to freeze, proceed through the easy-on cycle, and remain in the freeze mode. The instructor will then be able to deselect FREEZE to place the trainer in operation. The computation of platform positions will include washout and cue-limiting terms. These terms will be computed from the instantaneous actuator velocities and stroke remaining. The washout term will constantly attempt to return the platform to a desired steady-state attitude at a subliminal rate. Cue limiting will limit the onset acceleration actuators prior to engaging the hydraulic stops.

The platform-position terms will then be used as inputs to a computation of commanded actuator extensions for each of the six actuators. These terms will be outputed as analog outputs to the servo valve amplifiers.

Each actuator will have a position sensor to generate actuator position analog inputs. These terms will be used to compute the washout, cue limiting, and actual actuator pivot locations.

Hydraulic Power System

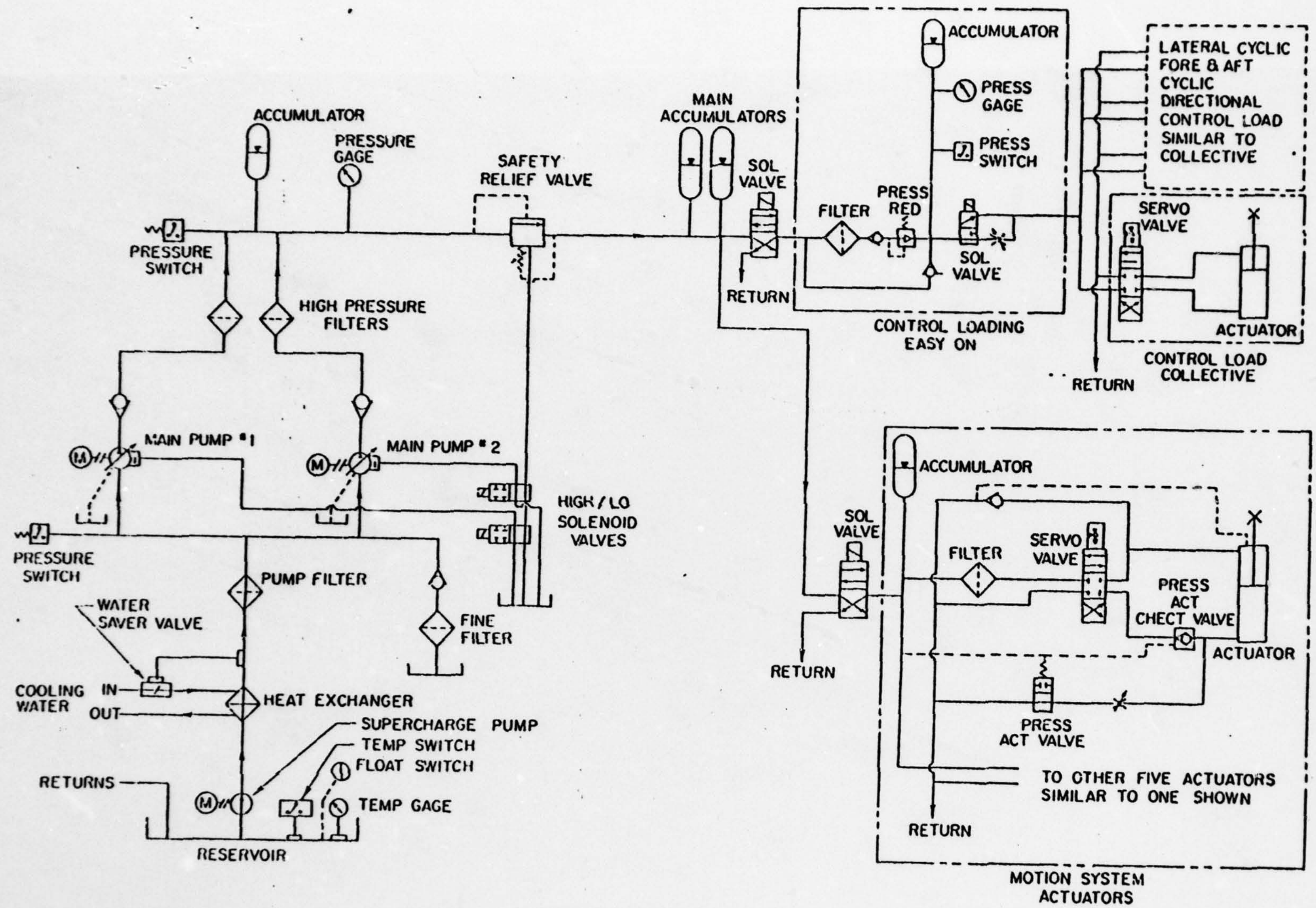
Figure 13 is a hydraulic schematic diagram of the hydraulic power system and the motion system. The design will incorporate an MTS System Corporation Model 506.81 hydraulic power supply. The rated capacity of this unit is 140 gallons per minute at an output pressure of 3000 psi. Some of the main features of this unit are:

- Energy-saving variable volume models pump only the fluid required. For additional power savings, operation of only one of the two pumps, when flow requirements permit.
- Water-conserving valve automatically controls cooling water flow to maintain proper hydraulic fluid temperature.
- Exceeds all JIC or OSHA standards for hydraulic equipment. Failsafe circuits automatically turn off the supply if an abnormal condition develops (fluid over temperature, low level, or pump motor thermal overload).
- HIGH-STOP-LOW functions controlled at the supply or via remote control panel allow safe start-up in low pressure and switching to high pressure.
- Pumps are rated for 3000 psi continuous duty and can be operated intermittently at up to 3500 psi.
- Filtration rated at 3 microns absolute which exceeds fluid conditioning requirements for reliable high-performance servovalve operation.

Hydraulic Power Unit

The hydraulic power unit will have variable-volume (pressure-compensated) main pumps with a pressurized inlet (supercharge). A screw-type supercharge pump draws fluid from the reservoir and forces it through a heat exchanger and a relatively coarse main-pump inlet filter that removes contaminants large enough to cause rapid pump wear. Fluid not required by the main-pump inlet returns to the reservoir through a 3-micron fine filter. A pressure switch on the supercharge line protects the main pump by turning it off if pressure drops below a safe level. Supercharge fluid passes over heat-exchanger tubes that contain cooling water. Cooling water flow is automatically varied by an adjustable water-saver valve which has its sensor immersed in fluid.

Since output flow varies automatically with external circuit demand, the main pressure control is on the main pump. No fluid is by-passed to maintain high output pressure but an adjustable safety relief



HYDRAULIC SCHEMATIC

Figure 13

valve will limit output pressure should the main pressure control malfunction. Output fluid is pumped through a check valve and then through a 10 micron high pressure filter to the external circuit.

The safety relief valve also has a vent port that is connected through a high/low solenoid valve to provide a low pressure condition. With the high/low solenoid valve energized, the safety relief valve vent is blocked and system pressure can rise to high pressure. With the high/low solenoid valve de-energized, the vent is opened, high pressure fluid is dumped to the reservoir, and output pressure falls to a low level. The low pressure conditions occurs: (1) automatically whenever the main pump motor is shut off (including electrical power failure and detection of an abnormal condition), (2) during supply turn-on for "soft start", (3) when the operator selects low pressure for low force, low velocity actuator positioning.

The accumulator has two functions. It reduces small pressure fluctuations by storing and releasing pressurized fluid. The larger accumulators allows use of servovalves having flows higher than the rating of the hydraulic supply, the difference in short-term peak flow being made up by the accumulator.

A control on the panel allows operation of one or both pumps as requ red. Also, the main pump vent ports are connected to the high/low solenoid valve so that, with one pump running, the second pump can be started in its low pressure condition.

Control Loading Hydraulic Supply

As shown on the hydraulic schematic, Figure 13, the control loading units will be supplied with hydraulic power from the hydraulic power supply unit through a solenoid control valve and easy-on unit. The solenoid valves for both the control loading and the motion system will be individually controllable. This will allow the control loading to be operated without the motion system. Also, in case of failure of one of the main pumps, the control loading can be operated from the other pump.

The easy-on system consists of a filter, pressure reducing valve, accumulator, and three-way solenoid valve. The pressure-reducing valve reduces the primary pressure down to 1200 psi for use in the control loading. When pressure is first applied to the system, the supply of fluid to the control loading is directed through the three way solenoid valve and ad-

justable restrictor valve to the servo valves. The volume of fluid passed by the restrictor will allow only very slow movement of the controls. A ten-second time delay relay controlled by the pressure switch shifts the three-way solenoid valve to place full flow to the servo valves. At any time hydraulic power or electrical power is interupted, the easy-on is automatically recycled. The easy-on assembly represented by the schematic has been used on all the A-4, H-3, H-52 and H-53 trainers previously designed by Sperry SECOR.

Motion System Actuators

Figure 13 shows a simplified hydraulic schematic for the motion system actuators. As shown, hydraulic fluid will be supplied to the six motion system actuators through a solenoid valve. The schematic diagram represents one of the six actuators. The other five actuators will be identical. As shown in Figure 13, each actuator will have an accumulator and high pressure filter in the supply line to the servo valve.

To prevent the motion platform from descending at an excessive speed in case of sudden loss of hydraulic pressure, an automatic easy-down hydraulic circuit will be included on each actuator. This circuit will consist of a pressure-actuated check valve in the line from the servo valve to the head end of each actuator. This will prevent the motion platform from descending if the supply pressure becomes too low for servo valve control. At the same time the pressure-actuated check valve closes, a pressure-actuated bypass valve and adjustable restrictor valve will allow a controlled rate of descent of the motion platform.

G-Seat Requirements

Motion systems, owing to their mechanical constraints, produce the most useful stimuli, or cues, during the onset phase of low-level, short-term accelerations. However, as the accelerations to be simulated become larger in magnitude and/or longer in duration, the capabilities of the motion system are approached and cue generation is constrained or terminated.

G-seats provide a useful method for partially simulating sustained high-g accelerations. The effect of the g-seat is to complement the motion system in the sustained and/or high-g motion regime.

G-seat technology has advanced sufficiently to justify technical

confidence in the concept, utilizing either pneumatic or hydraulic operating principles. Sperry SECOR has generated preliminary designs for both types of systems and will soon initiate a hardware development program aimed at design optimization, testing, and evaluation.

Since the technology is therefore available to provide a g-seat system, the primary objective of this section is to determine the requirement for utilizing this system in the AAH Trainer. The primary aspect of the requirement to be evaluated is, of course, the necessity for simulating sustained high-g accelerations. This requirement hinges on the training requirements and effectiveness criteria discussed in Section II of this Study Report.

Since the low-frequency flight motion simulation requirements developed in Section II do not include sustained high-g acceleration simulation, it is concluded that a g-seat system will not be required for the AAH Trainer. This conclusion is, of course, consistent with the study objective of defining the most cost effective AAH Trainer configuration, since a complex and expensive system is thus eliminated from the trainer configuration.

Vibration-and-Buffet System Requirements

The high-frequency motions and jolts, described as disturbance motions in Section II, are motions that should be simulated in both the AAH Full-Mission Trainer and the separate CPG Trainer. These motions can be readily simulated by the basic motion system for the Full-Mission Trainer and by a vibration-and-buffet system for the CPG Trainer.

Vibration-and-buffet systems are generally mechanized as either cockpit shakers or seat shakers. Sperry SECOR has designed both types of systems for trainer applications.

The cockpit-shaker approach provides practically total fidelity of high-frequency random-motion simulation, and this approach is recommended for the CPG Trainer.

The cockpit shaker system should be hydraulically operated and electrically controlled in response to computer-generated commands. This will allow for simulation of various disturbance spectra which will be stored in the computer program and outputed to drive the cockpit shaker in response to the total system simulation.

It is recommended that the system be mechanized to include two degrees of freedom of motion: lateral translation and vertical translation. This will provide the capability to more accurately simulate the complex cockpit-disturbance motions associated with helicopter rotor dynamics.

VISUAL SYSTEM MODULE

Introduction

This section of the study will address the components and technology of the visual system module.

It should be clear at the outset that the modules comprising the trainer are interdependent, so that selection of a specific configuration of one may dictate limitations or even elimination of others. In the visual system module area, for example, selection of a virtual image type display for the pilot and copilot/gunner (CPG) windscreen view dictates a two-cockpit configuration for the cockpit module. Also, selection of a motion system module may limit the choice of display techniques and even eliminate some available display hardware from consideration.

The visual subsystem includes all aspects of Image Generation and Display to the pilot or copilot/gunner, for any purpose. Thus, it includes not only the scene observed through the cockpit windows, but the pilot's and CPG's view (as applicable) through the Pilot's Night Vision Sight (PNVS), the Target Acquisition and Designation System (TADS) sensors, displayed on the Integrated Helmet and Display Sight System (IHADSS) and the gunner's panel displays.

In an earlier section of this study, specific training tasks were examined for the general applicability of model-board computer image generation, and film visual image techniques. Let us examine some of these tasks to derive more specific technical requirements of a visual system.

A key area is training for the terrain flight modes (NOE, low level, contour) plus landing and takeoff regimes. In daylight visual conditions, expected to obtain for 75-80% of all missions, the pilot and the CPG observe the scene through the cockpit windows.

Field of View

A major characteristic of these flight modes is their visual field of view. Figures 15 and 16, following, show the fields provided by the aircraft windows. As can be seen, the CPG, because of his forward position in the aircraft, has a somewhat more extensive field of view than the pilot.

Some study work has already been published by the Army as to what fields of view are required by the pilot to accomplish his piloting tasks in the AAH.* Figure 16 shows the results of these on the same scale as the pilot's vision plot of the YAH-64. As can be seen, the pilot is limited to about ± 125° in azimuth and can see down to the desired -30°, although not directly ahead. His upward view is extensive except for windshield mullion blockage. He can see well beyond the desired +30° for taxi, takeoff and landing, and the desired +45° for NOE flight. In the actual aircraft, his view grows toward 180° at his zenith, but this area is not utilized for these tasks.

In discussion of field of view with Cobra instructor pilots who had combat experience, the importance of maximum possible depression angle was emphasized. In contrast with the Fig. 17 plot, they deemphasized the elevation view, with 10-15° being considered quite adequate. During a flight in the front seat of the Cobra, it was clear that it was nearly impossible to twist the body while in the shoulder harness/safety belt to see beyond ± 90° in azimuth. Thus it appears that a realistic field of view for the simulator would provide the maximum depression angle that either crewman is capable of seeing, which Figs. 14 and 15 show to be -40°, and +15° elevation angle, for a total of 55° vertical angle. Azimuth angle should match the ± 90 which can be comfortably seen from the cockpit for a total of 180° horizontal angle.

*Army 5 Year Plan, appendix D, pg D-3

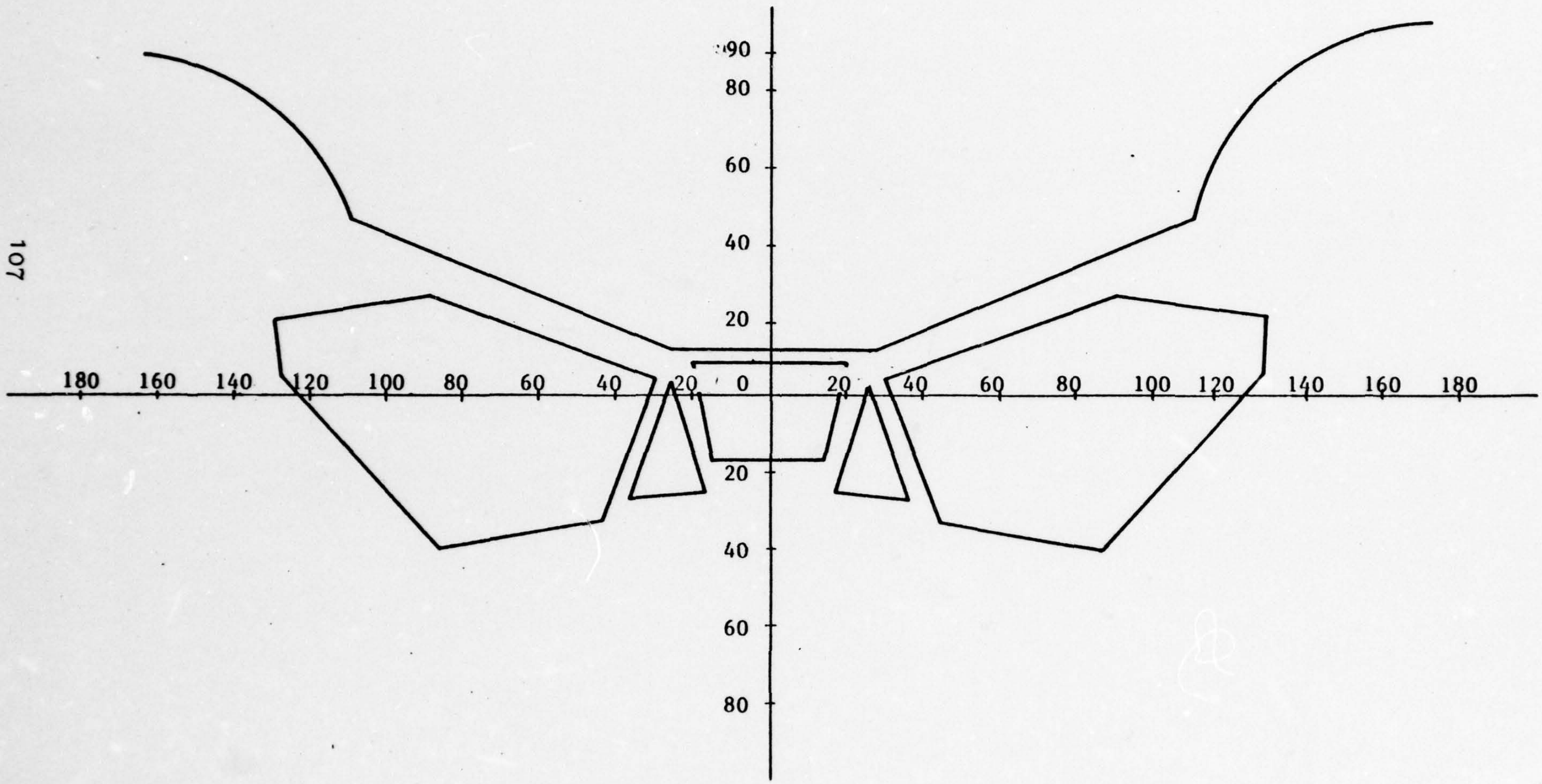


Figure 14
AAH PILOT VISION PLOT

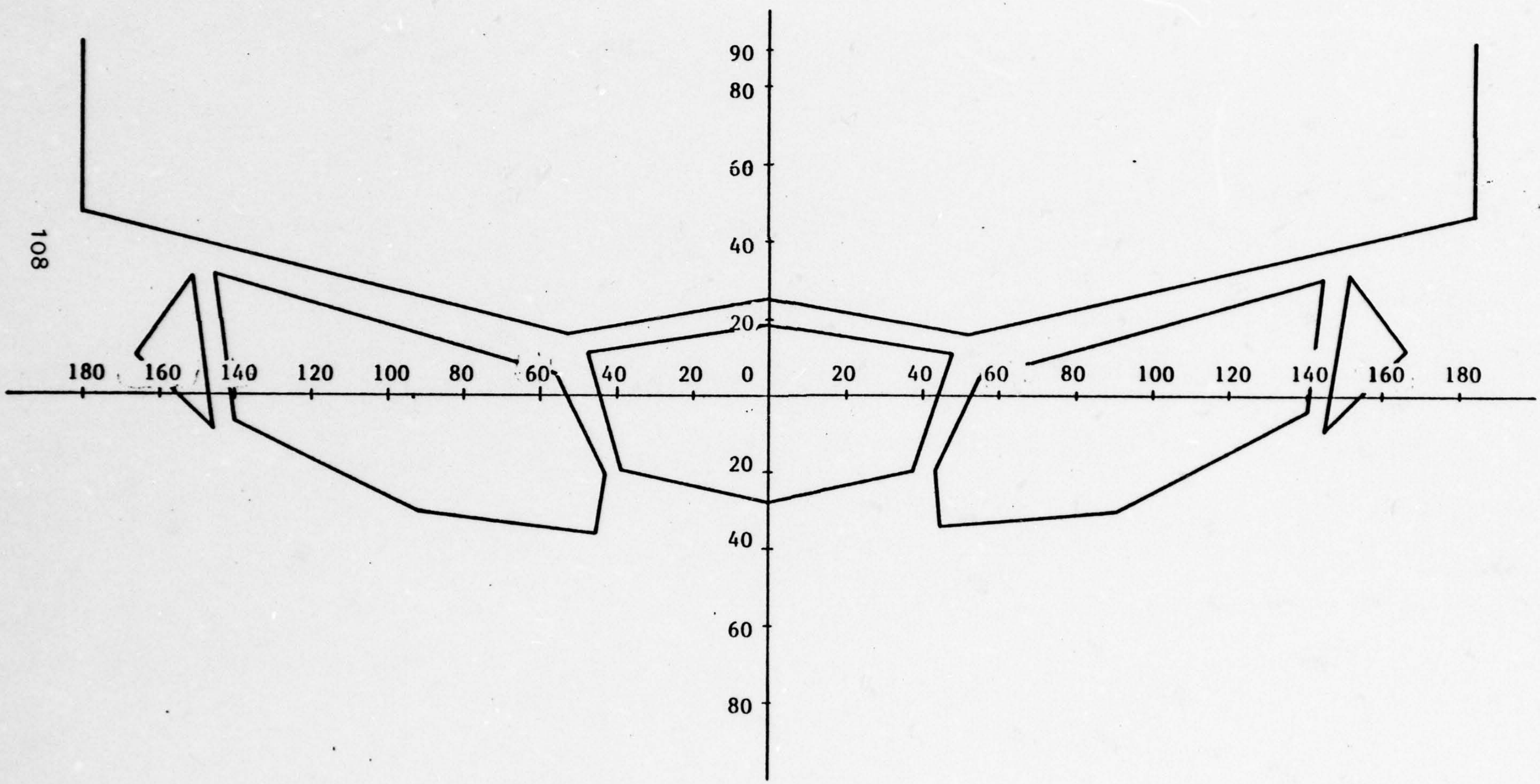


Figure 15
AAH CPG VISION PLOT

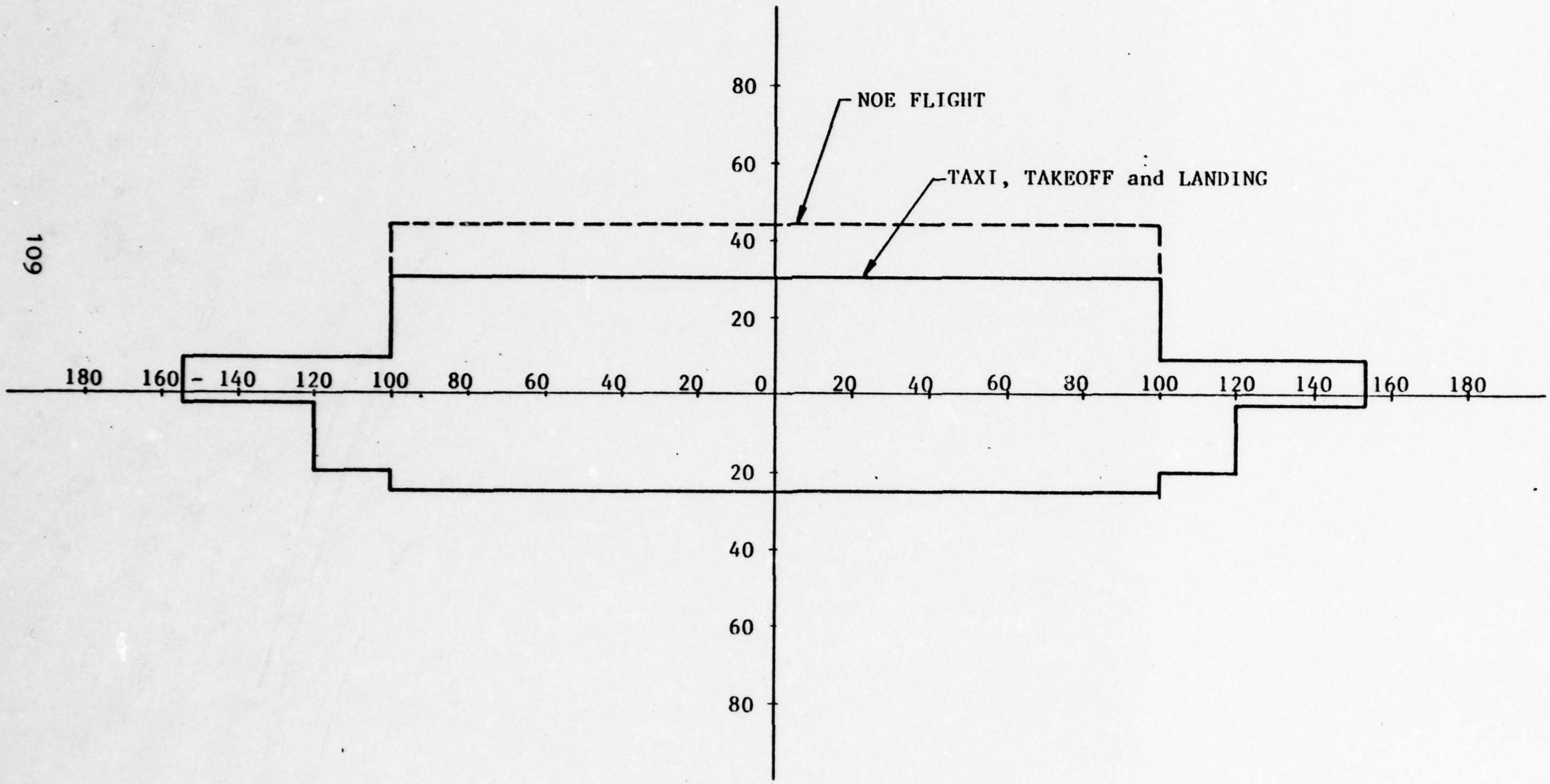


Figure 16
REQUIRED FIELD OF VIEW-ATTACK HELICOPTOR

Resolution

The next important characteristic for the pilot that is related to field of view is resolution. The desirable characteristic is to have real-world eye resolution capability, which is generally considered to be about 1 arc-minute. Coupled with the desired field of view, this would give a vertical resolution of 4,500 TV lines and a horizontal resolution of 15,000 TV lines at a 3 1/3-to-1 aspect ratio. Since these values are beyond the current state of the art, it is clear that some kind of compromise must be made between field of view and resolution. This compromise has been made on nearly all current systems in favor of retaining maximum field of view and accepting attainable resolutions from state-of-the-art image generation and display techniques.

Picture Quality

The next characteristics for these tasks relate to the more subjective aspects of picture quality.

Scene Brightness

The observed scene must be bright enough for the pilot to see clearly in a simulated daylight condition. From experience with other simulators, it is concluded that brightness of 5 foot-lamberts or better will accomplish this.

Color

The scene must be in color. For some aspects of terrain flight, color cues are highly important. For example, during NOE flight training, learning to stay concealed in forested, rolling country involves following creek beds to keep in the lowest part of the terrain. However, the creeks themselves are often invisible. The method of finding the path is to observe the trail of lighter green formed by the deciduous trees growing along the streams in comparison to the surrounding darker green pine or softwood stands. In

the navigation of the aircraft under these and similar conditions, color cues appear more important than textures.

Realism

In the design of training systems and programs, the goal of realism is ardently sought. Realism is complete in full scale operation of the aircraft, except that there are emergency operations that can not be done for reasons of safety. Combat simulation is "realistic" except that line of fire is restricted. Weather conditions are those existing at the time. Thus, even in the circumstances of greatest realism, there must be limitations for practical reasons. A prime objective is design of a system in which the proper level of realism is achieved to permit the broadest range of training tasks.

The simulation to be used in the AAHT will also be of limited realism. The visual system will be critically important to many of the training tasks. The designer must therefore be very careful to select the aspects of realism that are most vital to the training mission requirements, subject to constraints of technology and cost.

There is often a temptation to equate scene detail with realism. There is a relationship between a student's seeing windows on buildings and leaves on trees and his impression of a "real world" view. To the degree that leaves on the trees are important to training functions such as detection of concealed or camouflaged forces, they contribute functional (as well as cosmetic) realism. Extensive experience with relatively undetailed views in marine and aircraft simulators has demonstrated that functional realism can usually be achieved with limited detail as long as dynamic perspectives are maintained, surface shading is visually acceptable and moving objects in the scene behave as the viewer would expect the real article to behave. This is of great importance to

configuration selection when a choice must be made between strongly conflicting requirements. Of course, there must be a sufficient number and details of natural and cultural features and objects to allow accomplishment of specific tasks, such as maneuvering toward and around objects or terrain features.

The visual system will not provide scene brightness comparable to the real world on a bright day. Training is not cancelled on days when overcast skies lower scene brightness. Practical and achievable, though not fully "realistic," levels of scene illuminance can provide effective training in a functionally realistic way.

Night Operations

The pilot must also accomplish all the takeoff, flight and landing tasks at night. Depending on twilight, moon-phase, overcast or starlight conditions, some help may be obtained from the view out the windscreen. However, the primary night sensor is the Forward-Looking IR (FLIR) of the Pilot's Night Vision Sight (PNVS). For the PNVS, the relatively large field of view can be slewed by head motion, hand, or other controls through $\pm$ 90° azimuth and down to -45° elevation. Figure 17 shows the total field that can be covered by the PNVS instantaneous field. Thus, at night the pilot can see further towards his nadir than he can during the day, especially directly ahead, where the CPG blocks his view below about 25°. The scene observed on the Integrated Helmet and Display Sighting System (IHADSS) has the characteristics peculiar to the FLIR sensor of single color phosphor with video scene gray scales proportional to temperature differences, rather than reflected visible light. The pilot has essentially a monochrome area of interest (AOI) display at night of 30° X 40° which can be swept by his head motion through a wide azimuth and down to within

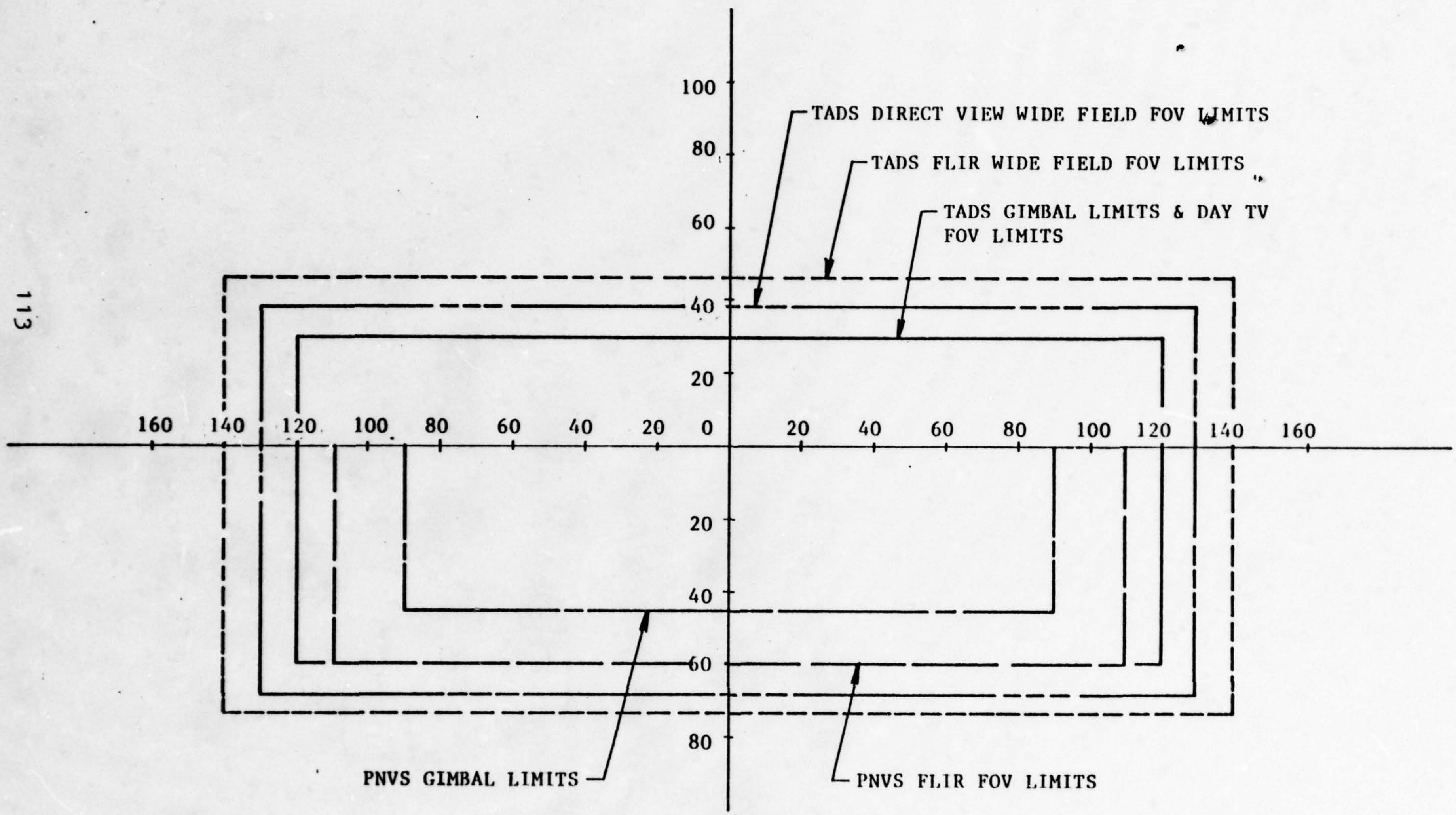


Figure 17
AAH TADS/PNVS SENSOR LOS LIMITATIONS

30° of the nadir. The CPG has an independent FLIR which has the identical instantaneous FOV and can be swept through an even greater azimuth (± 120°) but not as much below the aircraft. Thus, there are two independent AOI views that can look in different directions. This will certainly aid night navigation, although it complicates the trainer.

Viewing Aids

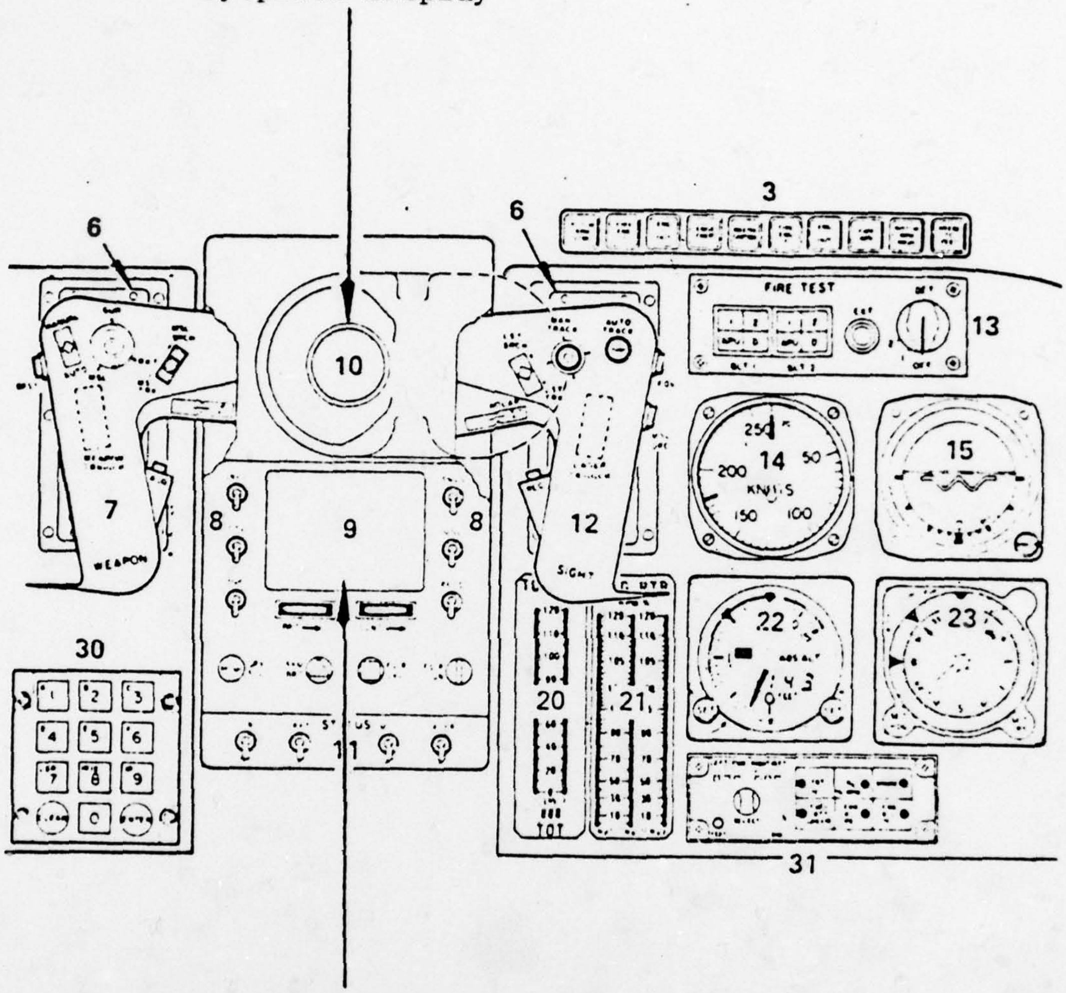
The pilot and CPG are both active in the task of target detection, recognition, and engagement. The pilot also has some tasks in threat engagement, but since the copilot/gunner has primary engagement responsibility, let us review his visual tasks and comment on the pilot as appropriate.

The CPG has, in addition to his view out the windscreen, the visual outputs of the three sensors of the Target Acquisition and Designation System (TADS). These include a direct view sight, a daylight TV with an extended red response sensor, and FLIR similar to that of the pilot.

The display for the CPG is a monocular eyepiece for the direct view sight, through which he can also select a display of the day TV, the FLIR or the pilot's PNVS FLIR. He also has, just below the eyepiece, a CRT display of about 4 inch size, on which he can select the outputs of any visual sensor except his direct view sight. Figure 18 shows the CPG visual display physical configuration.

The TADS sensors have considerable flexibility to aid the CPG in his detection, identification, and engagement visual tasks. Table 2 shows the field of view for each type of sensor plus the TADS turret gimbal angles through which their lines of sight can be directed. Similar data for the PNVS is included. Figure 17 shows these gimbal angles and fields-of-view excursions on the same scales as the pilot and CPG windscreen views. Comparisons show that the turret-mounted sensors give the AAH crew a larger total field,

Eyepiece Display



CRT for TV/IR Display

FIGURE 18. COPILOT/GUNNER VISUAL DISPLAYS

TABLE 2

TADS/PNVS SENSOR CHARACTERISTICS

SUBSYSTEM	GIMBAL ANGLE RANGE (AZ)	GIMBAL ANGLE RANGE (EL)	FIELDS OF VIEW VERTICAL/HORIZONTAL (All 3 x 4 Aspect Ratio)		MAGNIFICATION Panel CRT (20^o)	MAGNIFICATION Eyepiece (64^o)	MAGNIFICATION IHADSS HMD (30^ox40^o)
TADS	$\pm 120^o$	$+30^o$ -60^o					
FLIR (Night) (Pilot and CPG)			Wide	30^ox40^o	0.5	1.6	Unity
			Int.	10^o to 18^o	1.4	4.6	2.9
			Narrow	2^o to 4^o	6.7	21.0	13.0
Day-TV (Pilot and CPG)			Wide	2^o to 4^o	6.7	21.0	13.0
			Narrow	0.5^o to 1^o	27.0	85.0	53.0
Direct View (Day) (CPG Only)			Wide	18^o to 23^o	-	3.2	-
			Narrow	3.5^o to 4.5^o	-	21.0	-
PNVS	$\pm 90^o$	$+0^o$ -45^o					
FLIR (Night) (Pilot and CPG)				30^ox40^o	IHADSS HMD UNITY		

especially downward, than they have from the windscreen.

Thus, the simulator must enable similar instantaneous field of view (FOV) choices, the same total field, and the same visual characteristics as the TADS sensors, i.e., a very high-resolution color visual scene of either 20° or 4° FOV for the direct view sight, a monochrome scene of medium resolution with a 3° or a 3/4° field of view for the day TV, and a high resolution IR scene of 40°, 14° or 3° FOV for the FLIR.

The content of the observed scenes is critical to threat detection, recognition, and engagement training. The key task of the AAH is to engage tank and tank-like targets with missiles, and personnel or light-materiel targets with stowed weapons. Thus, the inclusion of such objects, with independent maneuver and motion capability, is a vital requirement on the visual subsystem. In addition, the ability of such moving targets to hide behind other objects in a realistic way, such as a tank hiding behind a terrain rise, will significantly enhance training effectiveness. The other aspects of an engagement scene, including missile plumes and trails, tracers, and weapon effects from own and friendly craft and from the threat array, are other important items of desirable visual scene content. For all moving objects, a minimum quantity of five is probably necessary, with up to 25 very desirable, for more realism to the total battle array. While target information usually comes from a friendly element, autonomous detection, identification, acquisition and engagement of threat targets are also required operating modes. Here, the emphasis must be on target and background model realism, and on the visual resolution necessary to accomplish detection and recognition at the proper ranges. While the specifics are classified, suffice it to say that the resolution requirements on the simulated visionic equipment in the trainer are quite severe.

Crew Coordination

With the capability for either crew member to see the windscreen visual scenes or any of the TADS/PNVS sensor scenes (except the direct view, available to the CPG only), the availability of visuals, with the above characteristics, together with functional simulation of the related controls, will enable the crew coordination vital to a realistic crew training mission. Such a mission typically involves receiving a target handoff, acquiring the target, selecting the proper weapon for target engagement and using the flight mode and technique of target attack best suited to the situation.

Little data on specific use of the visionics with the weapons systems was available, but from the specification data it would appear that a reasonable assignment and use would be as follows.

Daylight Operations. The gunner uses his windshield view, the direct view sight, and the daylight TV system for engagement using the Hellfire missile. A typical sequence might be as follows: The attack helicopter is ordered to an area where a scout aircraft has detected an armored threat. Enroute to the target area, the attack helicopter communicates with the scout and gets data on the target's grid location. At about 3500 meters, the attack helicopter uncovers. The gunner uses the direct sight in wide field to search the area of the target grid location. On detecting a possible target, he switches to the narrow field to recognize it as a tank and identify it as hostile. He then switches to the TV in wide field in which the target is slightly more magnified and uses the TV tracker to gate and lock on the tank. The panel CRT display allows the gunner to see "heads up". He then switches to the TV narrow field for better input

to the fire control system if conditions allow tracking to continue. Finally, the gunner triggers the laser designator (assuming that the scout is not laser-equipped) and releases the previously coded and selected Hellfire missile, which homes on the laser-designated spot to destroy the tank.

The pilot uses his IHADSS helmet mounted sight (HMS) normally to direct the 2.75-mm rockets for area fire, and the gunner uses his HMS to direct the flexible weapon. The weapons can be interchanged as desired although the CPG does not usually fire the rockets.

There is an extensive ability to exchange roles, with the gunner having flight controls and the pilot having the ability to use his IHADSS helmet mounted display (HMD) to see any sensors' video output. These are all used as backup modes or for emergencies (see Table 3).

Night Operations. The pilot uses his PNVS and sets a 30° x 40° field at 1:1 magnification on his HMD. The CPG uses his FLIR in wide field on his HMD to navigate while the pilot flies the aircraft. For target engagement, the CPG uses the FLIR sensor data displayed on the panel CRT to detect the target, recognize and identify it with progressively narrower fields of view, track it for fire control computations, designate it for missile launch or engage it with flexible or fixed weapons.

TABLE 3

PILOT AND CPG VISIONICS BREAKDOWN

	PILOT		GUNNER	
DAYLIGHT OPERATIONS	**Normal**	**Backup**	**Normal**	**Backup**
Sensor	Naked Eye	TADS TV	Naked Eye TADS Direct View TV	None
Display	None	HMD	Eyepiece Panel CRT	HMD
Sight Reticles	HMS	None	HMS	None
NIGHT OPERATIONS				
Sensor	PNVS-IR	TADS-IR	TADS-IR	PNVS-IR
Display	HMD	None	HMD	Panel CRT

Image Generation and Display Components and Technology

Overview of Technology. A number of techniques are available for consideration in providing the visual displays required for the AAH-Flight and Weapons Training System. Figure 19 shows a matrix summary of the primary alternatives for the out-of-the-windscreen scenes. In each case, the origin of the visual scene is shown at the bottom of the chart. Proceeding upwards in each case, the sensing, transmission and synthesis of the scene is shown. This group comprise the techniques of image generation. The upper columns comprise the image display methods, showing how the picture is projected, and finally how it is displayed for the observer.

As the matrix shows, there are these four basic approaches to picture production: filming a sequence of real-world events from a helicopter; projecting the silhouette of a three-dimensional model onto the screen by means of a point light source; generating the visual scene in a digital computer; and moving a television camera within a three-dimensional model. The first three approaches are quite compact, but space for the model board will be required if the television/visual model approach is selected.

Of the four, the cine-film technique is the simplest and least expensive. Panoramic camera and projection systems exist, and techniques have been developed for matching and blending the edges of adjacent pictures in multi-channel systems. The critical limitation, of course, is that such a display cannot respond to helicopter maneuvers; once filmed, the sequence of events is immutable. The usefulness of the technique is therefore limited to representing specific open-loop problems.

The Netherlands Ship Model Basin has developed a silhouette projection technique for its ship maneuvering simulator

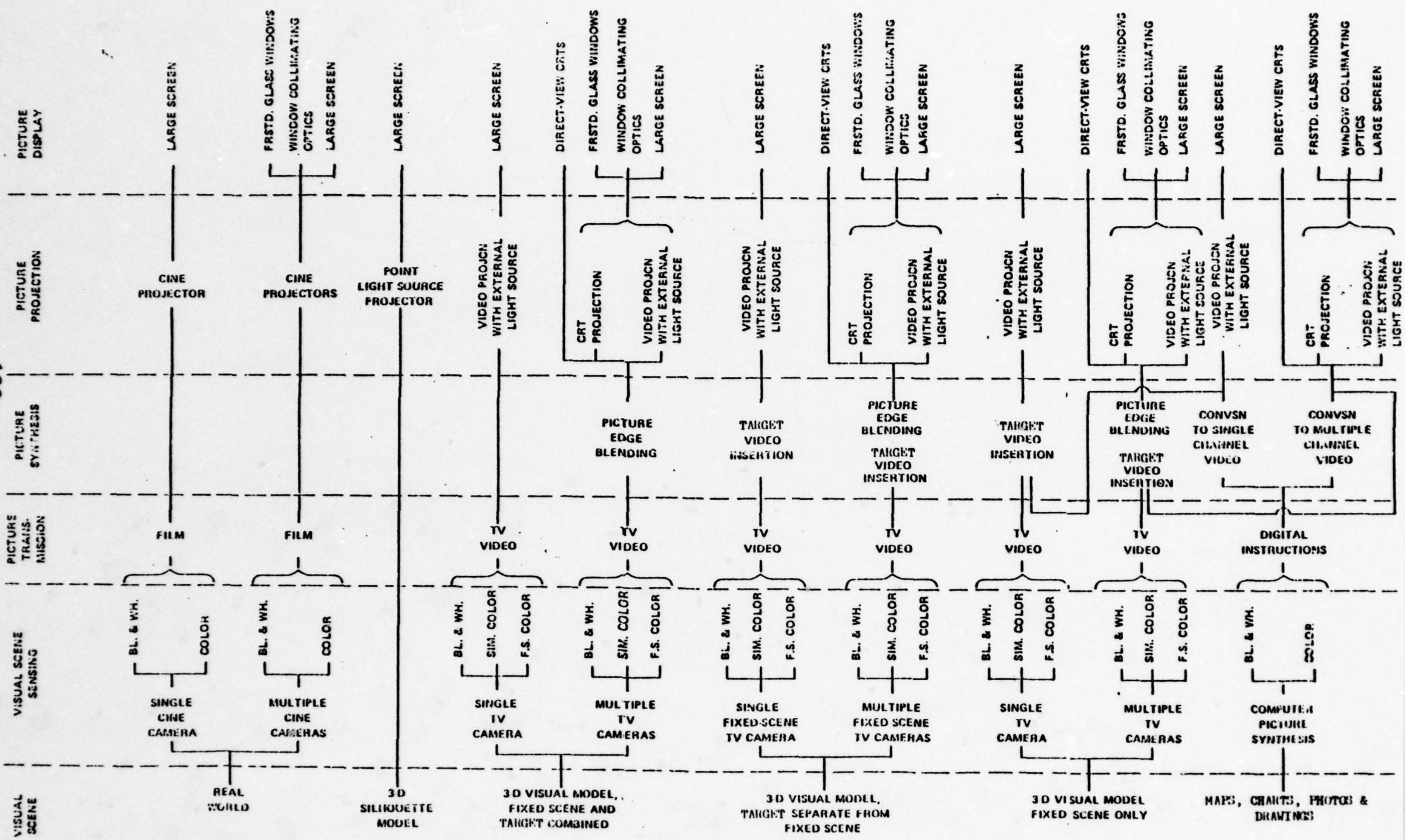


Figure 19. Visual Display Alternatives

in which the visual image responds properly to own ship maneuvers. A three-dimensional model of the visual scene surrounds a point light source at the center of a large, cylindrical screen. The light source throws shadows of objects in the visual scene onto the screen. Colored shadows are obtained by making the models of colored glass. Change in own ship position is represented by translating the model relative to the light source, changes in heading by rotating it about the light source. While this technique does provide maneuvering freedom, scale considerations necessarily limit it to relatively small areas; extension to larger areas would require frequent model changes. Moreover, the inclusion of a number of independently-maneuverable targets poses very serious engineering problems. This technique is too limited to be considered further.

Perhaps the most flexible way of producing a visual image is to generate it in a digital computer. A number of companies have developed techniques of computer image generation. The visual scene is made up of straight-line segments which constitute the edges of objects. The location of each edge in three dimensions is stored in the computer. Given the position of the observer, the computer synthesizes the appropriate view. The resulting computer instructions are converted to television video for display. Color pictures can be obtained by defining the color of each surface bounded by stored edges. One company has delivered a 4000-edge machine for ship simulation; displays with double or triple that number of edges are entirely feasible.

Picture quality is necessarily somewhat schematic, but scenes are readily recognizable and move with full dynamic fidelity. A major advantage is that representation of multiple movable targets presents no special problems.

The most life-like display is generated by using a three-dimensional visual model. One or more television cameras,

translated horizontally and rotated in heading by a servo-driven transport mechanism, represent the helicopter crews eyes. The model in such a system tends to be very large. Choice of model scale is governed by the requirement that significant objects do not become unmanageably small. If, for example, the model of an 8-foot-wide tank is to be at least 0.1 inch in size, model scale cannot be smaller than 1000 to 1. As a limit, a model scale of 2400 to 1 may be attainable by allowing small objects to be larger than life size. Even at this scale, however, a 20-mile route of flight requires 50 feet of model.

Representation of targets is another serious problem. To have several targets moving independently on the model terrain presents obvious difficulties. The alternative is to generate synthetic target video, and to insert it electronically into the fixed-scene video. This might be done by mounting off-scene target models on servo-driven heading turntables, and scanning them with one or more separate cameras. Scan conversion techniques can then be used to change image size with range, and to position the image properly within the frame as a function of target relative bearing. Standard television techniques are available for inserting the targets into the fixed-scene video. While the technique is technically feasible, it becomes complicated and expensive as the number increases. A possible alternative may be to mix computer-generated target video with the fixed-scene video from the scale model.

Once the composite video signals have been generated, they can either be viewed on cathode ray tubes through optics or projected onto display screens. For sighting aids on the helicopter, the cathode ray tube itself can serve as the projection light source, but a brighter source is required for large-screen projection. A number of video

projectors exist - for example, Gretag-Limited's Eidophor and General Electric's Light Valve - which use the video signal to modulate the light from a high-intensity light source. The scan circuits and the optics can be modified to conform to the simulator's field-of-view requirements.

Color television systems can make use either of simultaneous color or of field-sequential transmission. In simultaneous-color systems three separate video signals, corresponding to three primary colors, are generated and transmitted side by side. Bandwidth requirements for a given angular resolution are only slightly greater than for black-and-white video. The field-sequential approach eliminates the need for three separate video channels by transmitting the three colors in sequence on a single channel. In order to maintain the same overall frame rate, individual color fields have to be transmitted at three times the basic rate, and the system therefore requires three times the bandwidth of black-and-white video to retain the same resolution.

In addition to resolution, depth of focus and signal-to-noise ratio are important to picture quality. In the simulator visual display, the trees a few feet below the helicopter should be as sharply in focus as the target on the horizon. For the television camera, this implies a depth of focus from fractions of an inch to infinity. Large depth of focus can only be obtained with a very small aperture which, in turn, reduces the light entering the camera and consequently reduces the signal-to-noise ratio. Insufficient signal relative to inherent noise results in "snow" on the picture.

The design of a television system for the simulator must arrive at a suitable compromise between resolution, depth of focus, and signal-to-noise ratio.

Generation and Display Components

A variety of components are available for consideration in providing the visual displays required for the AAH flight and weapons training system. Some are mature and well tried, others are newer and still developing, and others are as yet untried and only in feasibility demonstration stage. Each has unique features which may be advantageous or disadvantageous for the AAH training problems. To bring some order to the evaluation of the technology and components, this section will list the methods available for image generation and discuss those characteristics pertinent to this training system. The same will then be done for the image display techniques. From this review, possibilities for the basic generation and display of the visuals, specific systems recommended for the visual system module will be justified using the training requirements as the driving force.

These configurations will then be reviewed and evaluated for their ability to meet the technical, availability, logistics and cost effectiveness criteria for the different visual modules required for the AAH training system.

Image Generators

Image generators fall into three broad categories based on the storage media of the visual data. The categories are:

1. Film-based generators
2. Model board generators
3. Computer image generators

Let us review what these image generators are, how they differ, and what characteristics make them unique. Table 4 lists the primary generator types and compares a series of specific characteristics with those that are desired for AAH

TABLE 4

AAH-FWS - IMAGE GENERATOR - MATRIX OF POSSIBILITIES

CHARACTERISTICS OF INTEREST

IMAGE GENERATOR TYPE	VIEWPOINT MOTION FREEDOM	SCENE DENSITY	MODEL REALISM	FIELD OF VIEW MAXIMUMS	RESOLUTION (OUT THE WINDOW)	NO. OF MOVING OBJECTS	MOTION FREEDOM MOVING OBJECTS	EXISTING SYSTEM EXAMPLE	TECHNOLOGY STATE/ FUTURE GROWTH	COST EFFEC-TIVENESS ESTIMATE	SPECIAL RESTRICTIONS OR CHARACTERISTICS
Desired characteristic for AAH training	Unrestricted	High-Real World	High-Real World	$\pm 90^{\circ}$ azimuth $+ 15^{\circ}-40^{\circ}$ EL	One arc-min.	25 or more	Unrestricted		Low risk-high growth potential	Benefit/cost ratio high	No special restrictions
Film generators camera/film	Severely restricted to minor variations from fixed path	High-real world	High-real world	360° AZ 50° EL	One arc-min.	None can be done by superposition	N/A	Fokker ship trainer	Low risk-little growth potential	Low	Film record or scene is immutable
Model board/TV camera/probe optics	Unrestricted within gaming area-limited in minimum height above surface	Can be high-near real world (Depends on modelling scale)	Can be high-near real world scale-dependent	$\pm 70^{\circ}$ AZ $+ 15-20$ EL (3 channels)	8 arc-min. (TYP)	Small - 1 to 5	Fixed paths only for required fields of view	2B33	High maturity -low risk-limited growth potential	Medium	Physically very large-may require special building - high power consumation limited to 3 channels by probe optics
Laser-scanned model board	Same as TV model board	Same as TV model board	Same as TV model board	$\pm 175^{\circ}$ $+ 20^{\circ}-40^{\circ}$	7 arc-min.	Same as TV model board	Same as TV model board	None existing	Very low maturity, high risk-but high potential in FOV vs resolution	Medium	Same as TV model board plus many unknowns
Computer Image Generator	Unrestricted within gaming area	Medium	Medium	Not restricted	Restricted only by computation-3 arc-min. systems in being	Can be high-5-25 or more	Unrestricted	ASUPT, CAORF	Medium maturity-low-risk very high growth potential	Medium to high	Requires special hard-wired processors. Requires special data base generation
Hybrid model board/TV with keying (video insertion) of moving objects (can be generated by CGI or TV camera/object model)	Same as TV model board	Same as TV model board	Same as TV model board	Same as TV model board	Same as TV model board	Can be high-1-10 or more	Unrestricted	LAMARS	Fairly high maturity. Low risk-limited growth potential	Medium	Physically identical to TV/model board. Moving objects always appear in front of background - they cannot be hidden by other parts of the scene

training. It also summarizes the cost relationships and technology status, with a conclusion about its applicability to an AAH training system.

Film Generators. Generating film visuals is simply a matter of taking pictures of the real world with one or more cine cameras. The film storage medium then forces the display to the cine projectors. The state-of-the-art in film and film cameras is highly developed and mature. Very high resolution cine pictures can be taken of wide or narrow angle views and mated to show even 360° azimuth scenes. Object density in the scene faithfully reproduces the real world, and resolution on large-format film (such as 70 mm) with proper design of multiple camera installations for the total field desired, can meet almost any requirement for detection and recognition at ranges comparable to those in the actual situation.

Generating film for a flight simulator involves flying over the desired terrain with an airborne camera installation. Thus, if specific terrain locations are desired, it must be in the power of the visual generating agency to accomplish the fly-over. Also, if any other moving objects, friendly or threat, are to be simulated, they must be available and under control also. This is not a restriction in domestic or allied territory, but is a significant one for potentially hostile areas.

Perhaps the most significant limitation of film generation (and display) for simulation purposes is the fixed nature of the results. Once taken, film allows only the reproduction of those specific positions and conditions with little or no variation.

Thus, its application is limited to essentially open-loop simulation. The significant advantage is widely-

available, flexible, mature components at relatively low cost to accomplish the image generation task.

Model Board Generator. Model board visuals are television pictures of a scaled physical model of an area of terrain containing features or objects of interest. The pictures are produced by an optical probe and one or more television cameras mounted on a servoed gantry system so that the viewpoint can be controlled in position and altitude in relation to the board. The optical system has very stringent requirements including good resolution, wide field, large depth of focus, large aperture, and small physical size to allow close approach to the model board. These conflicting requirements result in long, narrow optical probes that can show perhaps a maximum field of 140° in azimuth and have very small apertures for reasonable depth of focus. Such systems require high light levels on the model board to get enough light through to the TV camera faceplates, making power consumption an operating cost problem.

However, TV camera/probe scanned model boards make up the bulk of existing image generators for flight simulators. Model boards have been a preferred environmental scene storage method for a number of advantageous characteristics. Chief among these is the ability to accurately reproduce terrain contours, and natural and cultural visual features. A high order of fidelity in scale and in object details has been achieved as model making was improved and photo transfer techniques have been applied. Model board generators can produce very high scene object densities and, with proper gantry/TV camera/optical probe sensors, provide highly realistic visual scenes of the environment from a moving aircraft. The choice of scale for the model board is very important because the total area modeled vs. the amount of detail physically achievable in

each object must be traded off. Where the range is too wide for reasonable compromise, either multiple boards of different scales must be used or specific areas of one board can be modeled to different scales and scale switching arranged. Another approach is use of very large boards which then become a space and power problem, requiring special buildings and consuming significant energy.

Another serious limitation of model board generators is the difficulty associated with having moving objects in the field of view. Because the scene to be observed is produced from a real scene in miniature, moving objects in the observed scene must also be in the real scene in miniature. This drastically limits their motion capabilities because of the physical restrictions involved. Moving miniatures propelled via slotted pathways or moving magnets have been used but these are restricted to relatively simple preprogrammed pathways which may limit their use for training. While radio-controlled models are possible with full motion freedom, the scale of models required is incompatible with present independent control systems which are relatively large, complicated and unreliable. It is also possible to key in (insert) video from a separate source to show a moving object that has an unprogrammed path. This method is limited, too, since it cannot show the moving object hidden behind other objects of the static scene. In addition, as scale and perspective of the static scene change to a moving observer, the system must do the same to the moving object to maintain compatibility in the combined scene. A refined version of such a moving object system may be the best that can currently be planned for a model board image generator, despite its shortcomings.

In summary, model board generators have been developed over the past several decades and the technology is quite mature. The refinements are essentially all in place and major improvements over existing systems await

technological breakthrough which cannot be foreseen, rather than further development.

One such technological breakthrough is being attempted by NTEC with Air Force support in the wide angle laser scan system. This is a model board generator where the picture output is developed by a laser based system wherein a raster scanned laser beam's reflection from a model board is picked up by photomultipliers whose outputs are combined and processed to form video signals. Feasibility studies have been completed and a breadboard model is under contract. The key advances being sought in this program do not relate to the model board limitations addressed thus far, but to obtaining a wide field with adequate resolution in a single channel.

Sperry has been favorably impressed with the depth and extent of the feasibility and breadboard work to date on the wide-angle laser scan system and its potential for the AAHT application. The development of a practical and usable visual system requires significant advances in several areas of laser technology and thus there is significant risk in considering it as the primary image system for a scheduled program. One area, that of 100 MHz laser modulator technology, Sperry believes is not now near a solution. Two specific technical problems are outlined below. Both are based on data from the American Airlines final report on the WALVS feasibility study. The first shows that the modulator crystal will experience a serious temperature rise and the second that the modulator will require very high drive power due to dielectric power losses.

<u>Heating Effect in Birefringent Crystal</u>

Assume all heat transfer from crystal is by radiation.

$\frac{\text{Power}}{\text{Area}} = E_t \sigma (T^4 - T_o^4)$ ITT Handbook 4 ed. p. 369

E_t for glass = 0.94 at 293°K AIP Handbook 1957 p. 6 - 71

$\sigma = 5.67 \times 10^{-12}$ watts/cm^2 $°K^{-4}$

For best case, T_o is room temperature = 293°K

Area for crystal $\frac{1}{2} \times \frac{1}{2} \times 2\frac{1}{2}$ inches

$A = \left[2(\frac{1}{2} \times \frac{1}{2}) + 4(\frac{1}{2} \times 2\frac{1}{2})\right] 6.25 = 34.38$ sqcm

$T^4 - T_o^4 = \frac{P}{A_{E_t}\sigma}$ and $T^4 = \frac{P}{A_{E_t}\sigma} + T_o^4$

Assume power dissipated in the crystal is 2 watts

$$T^4 = \frac{2}{(34.38)\ (.94)\ (5.67 \times 10^{-12})} + (293)^4$$

$$= 1.828 \times 10^{10}$$

T = 367.72°K or a temp rise of <u>75°C</u>

Power Consumption in E-O Modulator

Dimensions of capacitor plates: 5 X 0.5 inches-

spacing 0.5 inch

Based on p. 110 of AA report

$C = 0.225\ E_r \frac{(N - 1)\ A''}{t''}$ uuf pg. 133 of ITT Handbook '57 ed.

E_r = 90 for KDP pg. 5 - 155 AIP Handbook '57 ed.

$C = 0.225\ (90)\ \frac{2.5}{0.5} = 101.25$ uuf

Power lost in dielectric

$W_e = wCV^2 \tan\delta$

$\tan\delta$ for KD*P is 5×10^{-4} per Eo Vaher

$$W = 2\ (10^8)\ (10^{-10})\ (3)^2\ 10^4\ (5 \times 10^{-4})$$

$$= 2.83 \text{ watts}$$

$$\text{Drive power} = fCV^2 = (10^8)\ (10^{-10})\ 10^5 = 10^3 \text{ watts}$$

These kinds of problems may cause delays or lower than expected performance from the wide angle laser scan system. Thus, completion and evaluation of the breadboard model is necessary before any decision to apply this visual technology to the AAH trainer can be taken.

Computer Image Generators. Computer image generators are a relatively recent development in simulation. Starting only in the last half of the 1960's, computer generated imaging (CGI) technology has experienced steady growth in capability, capacity, flexibility and applications, expecially in simulation. Not only is no end to this growth in sight, but acceleration of development is more probable than deceleration. Computer image generators are oriented heavily toward memories, and the rapid growth of memory technology, witness CCD and bubble memories, will sustain continued advances in CGI.

Computer image generators store visual data in the form of locations of object points or vertices in three dimensional space in a computer mass memory, such as a disk. The total stored material is called the data base. The CIG system extracts that part of the data base that can be seen from the observer's position and holds it in an active storage memory. Every television frame time, the three-dimensional object data is taken from the active memory, transformed, and placed in proper perspective projection in two dimensions as it would be seen by an observer. The two dimensional perspective data is scan converted to TV raster format, parts of objects hidden by other objects are detected and removed and the resultant digital data is converted to analog video signals at television rates. Since standard

TV rates in the United States require 30 picture frames per second, the image generator, parts of which are high-speed, hard-wired digital processors, recomputes a new picture every 1/30 second.

As with model board generators, the architecture of the computer image generator leads directly to both its strengths and limitations.

The data base is modeled by converting maps, charts, drawings or photos of natural and cultural objects into digital form. The conversion process, although partly automated, is under the control of a human modeler. The modeler must know the parameters of his generator and the visual results desired, because his primary task is to make the most effective use of a finite equipment capacity to produce the desired scenes. Because the computer image generator can store a specific number of points or vertices, and can process only a part of these in a 1/30 of a second through to display, the resulting visual scene has a limited amount of detail at any moment.

The modeler also has constraints on how to model objects. If he models them with too few vertices they will look quite unrealistic, like a poorly drawn cartoon. If he uses many vertices or "edges" (which are the straight lines between vertices) he may rapidly use up most of the storage or processing capacity of the generator before it can display all the objects he wants to be able to see.

Thus, for a wide field of view, in conditions where there are many details we want to see in the scene, computer image generators are limited to showing only a certain amount of detail and no more. This capacity may be utilized to show a large number of low detail objects or a smaller number of highly detailed objects.

One significant characteristic of CGI is the ease of placing moving objects in the visual scene and the flexible way in which they can be inserted, moved and removed. Since the generator reaches into active memory for object locations and processes a new set every 1/30 second, all we need do for a moving object is to calculate its position in space at that rate and place it in the active memory. In fact, this is done for a single point of the object, its centroid; and the generator takes the object itself such as a tank, from a part of the memory and places it at the new centroid location every 1/30 second. Thus, there will be a tank in the scene which can move on any path chosen by an instructor, a stored scenario program or even a tank driver operating remote controls. A number of threat vehicles can operate independently and simultaneously, but they contribute to the limited total scene edge capacity of the generator.

Conclusions and Recommendations on Image Generators

It is clear from the review of image generators technology that no single generation technique provides all the desired visual characteristics for accomplishing the required AAH training in a single trainer configuration. Sperry SECOR has chosen to recommend a training system composed of an integrated pilot/gunner trainer, a separate gunner trainer, and the YAH-64 aircraft itself, partly because of this fact.

The breakdown of major crew member tasks and their effect on image requirements have been detailed elsewhere in this report. The resulting choice is to optimize the visual simulation separately for the gunner and the pilot, while still providing the best available capability for crew integration. The gunner, who does not directly control the aircraft flight, has tasks requiring very high resolution. For his trainer, then, cinematic techniques offer the detailed realism and high resolution required for the out-the-windscreen view. The open loop nature of the film visual system is not a serious handicap in training the man who does not fly the aircraft.

The choice for the pilot/gunner image generator is less clear. While the emphasis in the pilot/gunner trainer is on the pilot, it is vital that crew training be considered, so integrated tasks must be able to be trained. Many of these involve use of the TADS/PNVS sighting aids. Visual requirements for these sighting aids were discussed earlier in this section. When these are combined with the out-the-windscreen view requirements for both crewmen, a formidable visual simulation task emerges.

Table 5 is an attempt to summarize the requirements for a system to do pilot/crew training. It lists the parameters considered, and shows for each how the model board and computer image generation approaches would compare. Because of the closed loop nature of the pilot and integration training tasks, film is not considered.

When the comparison is put on this basis, the advantages of CGI show up rather clearly. These advantages include the flexibility of controllable moving targets, independent narrow field-of-view scenes for the sighting aids, simple IR scene simulation integrated with the day/night scene data base, and ease of simulating weapon effects. CGI exchanges more lifelike realism in scene object quantity and details for a controlled detail level representational model scene. For these reasons, CGI is the image generation system selected by Sperry SECOR as the first choice for the pilot/gunner trainer.

If the wide-angle laser scan system can make the technological breakthroughs needed, and demonstrates that it is sufficiently practical for use in the AAH trainer, then the visual system for the pilot/gunner must be reevaluated. The laser scan system can substitute completely for the windscreen display for the pilot/gunner trainer. However, it

TABLE 5

AAH PILOT/GUNNER TRAINER

VISUAL SIMULATION SYSTEM

PARAMETER	MODEL BOARD APPROACH	CGI APPROACH
1. Scenery content; terrain contour, terrain texture, vegetation, trees, curves, hills, gullies, ripples.	Lifelike scene detail, resolution limited by TV system.	Representational models, limited by CGI Processor capacity, data base modelling level and real-time software. Newest techniques can assure all capacity is used to place only visible, significant scene elements on display.
2. Moving targets; random direction, varying range, varying speed, various target types (soft,hard)	1. Pivotal Track - Limited Range 2. Radio Controlled Magnet Coupling - Horizontal model bd. 3. Inset with camera and scan conv. - accuracy problem 4. Separate gantry - accuracy problem	Moving targets easily implemented with multiple moving coordinate systems. Target position and heading computed in central data processor and visual system places selected model at those locations in real time. Instructor or software can control target direction, speed, range and type.
3. Optical viewing, magnified for TADS/PNVS	1. Reimage full scene in probe with high resolution camera onto: a) Scan Converter b) Secondary screen and camera servo	Two separate CGI pipeline processors driven from the same host computer with one data base.

4. FLIR sensing TADS/PNVS	1. Simultaneous IR model board and gantry	Data base coded for both daylight color and IR gray scale proportional to temperature in the proper IR band. Choice of day or IR operation activates data base code.
5. Weapons effects; flash, smoke, tracers, missile plume.	1. Inset flash, smoke and dust with mech. gen., camera and scan conv. to provide size and position control under computer control.	Weapons effects at remote locations modelled in data base and called up in proper position and time by central data processor. AAH firing flash, smoke can be modelled as colored haze, partly obscuring all objects from view. Tracers modelled on moving coordinate system driven from CDP.
6. Day/Night; landing lights, cultural lights	1. Landing lights - lights on probe illuminating the path - system lights out 2. Cultural lights - use of fibre optics.	On board and cultural lights modelled in data base at proper intensity, modified by range to own AAH to limit of display dynamic range of brightness. Path illumination provided by simulated directional illumination lobes from on board lights interacting with objects in flight path, returning realistic intensity variation.
7. Simulated eye heights	1. Simulated with the scan converters as part of item 3	Parallax of naked eye view minimized by screen distance. IHADSS directional pointing angles corrected by CDP for parallax. Magnified sight images corrected for eye height in CGI system.

8. Image quality; dynamic fidelity to judge velocity, rate of closure	1. Requires a high resolution, low lag camera tube such as the 4" Image Isocon. Lag is limited to 2% at 50 ms. Resolution is 1000 TV lines.	Resolution of 1000 TV lines feasible. All perspectives are correct, so cues of image size growth rate, object motion and occulting are proper. Missing cues are changing fine details in near field - not modelled.
9. Visual cues; image detail and dynamic system performance.	1. Visual and motion cues exist from the texturing done on the model board surface.	Selected level of modelling provides chosen detail and true and visual cues for those objects. See above for motion cues. Dynamics do not degrade visual quality until rates causing physical separation of TV raster fields.
10. Line of sight; for TADS/PNVS	1. Multiple probes - problem of different eye points 2. Multiple model boards and gantry	CGI processor produces 240° instantaneous scene, so pilot and gunner can see over wide field. Separate CGI channels needed for independent magnified views.
11. Performance trade-offs. Order of precedence: 1) Resolution 2) Dynamic realism 3) Scene brightness 4) Distortionless image	1. Resolution - Practical System limitations of 7-8 min/L.P. 2. Dynamic Realism - limited by camera tube - with an Image Isocon - 2% lag at 50 ms. 3. Scene brightness - depends on proj. and screen width	1. Resolution - CGI system can be built for any resolution. Multichannel displays may be needed to produce that resolution for the eye - cost/power/performance tradeoff. 2. No limitation to dynamic realism. CGI produces every element of every picture digitally. Assuming proper video bandwidth, dynamics must cause raster field separation to cause picture distortion.

	5 Ft.-L. practical. 4. Distortionless Image - requires Distortion and Scan correctors for the cameras	3. Screen brightness same as model board - function of display - 5 ft.-Lamberts practical 4. Pictures generated without distortion. Projection geometry may cause distortions, but optical, electronic or picture generation distortion corrections can be applied.
12. Refresh rate 30 FR/sec.	1. Standard of 30 FR/sec, 60 FLDS/sec for B/W 30 FR/sec, 180 FLDS/sec for field seq. color	Same standards as model board. Digital picture is produced asynchronously, so any type of TV SYNC standards can be used.
13. Contrast ratio; 15:1	15:1 contrast ratio practical	Function of display - 25:1 contrast ratio practical
14. Stability; 0.5% min. of height	No data	Picture generation stability $\pm \frac{1}{2}$ resolution element. Display stability of 1 resolution element practical. This is $\frac{1}{4}$%.
15. Luminance; 5 FT.L., uniform to 30%	1. Achievable with unity gain screen.	Luminance practical. Uniformity depends on display geometry - may need low gain screen.

cannot readily provide the video inputs for the TADS/PNVS displays. Thus, a laser scan based visual module would likely need to be a hybrid system because of the wide range of integrated training requirements.

Image Displays

Image displays are of two basic types. Real image displays present an actual picture on a surface, such as a screen or CRT face, which can be seen by observers. Virtual image displays place an optical system between the real image and the observer's eye so that the image appears to be located at infinity to the viewer. Any of the real image display methods can be used as the image input to a virtual image display.

Table 6 lists the image display components and makes comparisons to desired characteristics, as in the previous chart on image generators.

Real Image Displays

Film projector/screen. Film projectors, showing images on a screen, are familiar to all. Capable of high brightness, large-screen projection systems are well-developed, and techniques of matching and blending the edges of adjacent pictures in multi-channel systems are in common use. The limitation is still that the display cannot freely respond to own aircraft maneuvers. For open-loop training situations, however, the high-resolution, wide fields of view, economy, and mature technology of film display make it an attractive choice.

Video Projectors. All the non-film image generators produce TV video as their outputs. This video can be displayed directly on a TV monitor CRT, and for the simulation of the cockpit displays from the TADS/PNVS, this is suitable. For the outside view, however, a large field of view is needed, and, for real images, some form of video projection technique must be used.

Projection CRT. One long-used technique for showing large screen video pictures is to use a high-brightness CRT and an optical system to project it on a screen. The current

TABLE 6

AAH - FWS IMAGE DISPLAY - MATRIX OF POSSIBILITIES

IMAGE DISPLAY TYPE	FIELD OF VIEW - CHANNELS	RESOLUTION	SCENE BRIGHTNESS	LUMINOUS OUTPUT FLUX	COLOR TYPE	AVAILABILITY (SCHEDULE FOR FIRST UNITS)	TECHNOLOGY STATE - FUTURE GROWTH	COST-EFFECTIVENESS ESTIMATE	SPECIAL RESTRICTIONS OR CHARACTERISTICS
Desired characteristic for AAH training	$\pm 90^{o}$ azimuth $+ 15\text{-}40^{o}$ elevation	One arc-min.	At least 5 ft. lamberts	Enough to give desired scene brightness	Full color	Available in mid 1979	Low risk-high growth potential	Benefit/cost ratio high	No special restrictions
<u>Virtual Image</u>									
Mirror/Beamsplitter	$\pm 25^{o}$ AZ per $\pm 20^{o}$ EL channel Difficult to abut channels	3 arc-min.	15-20 ft.-lamberts	80 lumens EKT	Simultaneous color	Available now	High maturity, low risk-low growth potential	Moderate-high	Forces a two-cockpit configuration. Good for single observers only - hard to mate for multichannel display. Relatively simple and light.
In-line infinity optics (pancake window)	$\pm 45^{o}$ circular inscribed pentagon to butt for multi-channel	5-6 arc-min.	About 1 ft. lambert	Requires 100 lumens or more	Simultaneous color	Available now	Medium maturity and risk - good growth potential	Moderate	Forces a two-cockpit configuration. Good for single observers only. Can be mosaicked for large fields but scene is imperfect across channel edges.
<u>Real Image</u> (projector/screen)									
Film projector	Unrestricted for multiple channels	One arc-min.	15-20 ft. lamberts	3000 lumens	Color film	Available now	High maturity, low risk-medium growth potential	Moderate	Very high resolution - low cost, but no control over filmed flight path.
Projection CRT/screen	Unrestricted for multiple channels	3 minutes	3.3 ft. lamberts	500 lumens	Simultaneous color	Available now	Technology mature, medium risk, low potential	Low	No tilt restrictions - CRT life short for high outputs
Eidophor projector/screen	Unrestricted for multiple channels	3 minutes	25	7000 lumens 900	Simultaneous color or field sequential color	Available now	Technology mature, low risk - little potential	Low	Very large and heavy - cannot be mounted on motion platform due to tilt and oil film restrictions. High operating/maintenance costs.
GE light valve/screen	Unrestricted for multiple channels	3 minutes	6.67	1000 lumens	Simultaneous color	Available now	Technology mature-low risk-medium potential	High	Limited in tilt. BLT can be mounted on motion platforms, $\pm 45^{o}$ pitch and roll (cyclic).
Liquid crystal projector/screen	Unrestricted for multiple channels	3 minutes	4.6	1600 lumens	Simultaneous color	800 lumen monochrome available now, 1600 lumen color scheduled for 1979	Technology developing-medium risk-high potential	High	Relatively small and lightweight. No tilt restrictions. Operation and maintenance costs low.

TABLE 6 (cont'd)

AAH - FWS IMAGE DISPLAY - MATRIX OF POSSIBILITIES

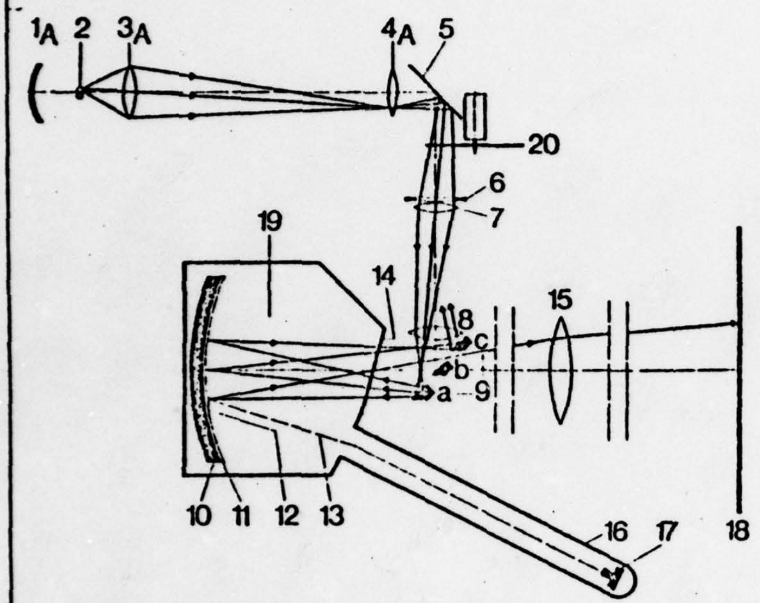
IMAGE DISPLAY TYPE	FIELD OF VIEW - CHANNELS	RESOLUTION	SCENE BRIGHTNESS	LUMINOUS OUTPUT FLUX	COLOR TYPE	AVAILABILITY (SCHEDULE FOR FIRST UNITS)	TECHNOLOGY STATE - FUTURE GROWTH	COST-EFFECTIVENESS ESTIMATE	SPECIAL RESTRICTIONS OR CHARACTERISTICS
Laser scanning projector/screen	175^{o} AZ single channel $+20^{o}$ - 40^{o} EL	7 minutes	10 ft. lamberts	430 lumens	Simultaneous color	Breadboard unit scheduled for late 1978	Feasibility study done. Breadboard model in development, high risk-high. potential	Moderate	
360^{o} projector/screen	360^{o} AZ $+20$-40^{o} EL 12 channel	9 minutes	10 ft. lamberts	Unknown	Simultaneous color	Feasibility model scheduled for late 1978	Initial development and breadboard effort underway at NTEC. Very high risk-high potential	Unknown	

Advent commercial and home projectors are an example of this type. Projection CRTs have been limited by inability to make a reasonably bright display for large screens without such exotic techniques as sapphire faceplates and high voltages, with resulting problems with cooling, life, and replacement cost. Phillips, Aydin and Aeronutronic-Ford, among others, have produced large-screen display projection systems using CRTs.

Light Valves. Instead of trying to obtain enough light from a phosphor, several light valve techniques have been developed and are being successfully used for the largest video displays in existence. The light valve uses the TV video to control the output of a high-brightness continuous light source such as a xenon arc lamp. In these equipments, black levels in the video cause the incoming arc lamp light to be reflected back to the lamp, while the white video changes the lamp light so that it is sent out through projection optics to a screen. We will discuss three forms of light valve which might be applied to the AAH-FWS.

Eidophor. The Eidophor video projector is a Swiss-made device that uses an oil film which is written on by an electron gun as its light valve. Figure 20 shows a sketch of the Eidophor principle. A xenon arc lamp light source is directed to a rotating mirror through a Schlieren mirror bar optical system. A special oil film covers the mirror. Where the electron gun has written a TV line on the oil, the hills and valleys produced in the film by the non-black elements cause the reflected light to pass through the bars of the Schlieren mirror and are imaged on the screen by the projection lens. Black elements do not disturb the oil film and the reflected light hits the mirror bars and is returned to the light source.

EIDOPHOR PRINCIPLE



1A	AUXILIARY SPHERICAL MIRROR
2	- -EXTREME POINT OF THE LIGHT SOURCE
3A	CONDENSER LENS
4A	CORRECTION LENS
5	COLD MIRROR
6	PICTURE WINDOW
7	CONVERGING LENS
8	FIELD LENS
9a,b,c	BAR SYSTEM
10	SPHERICAL MIRROR
11	CONTROL LAYER
12	PERTURBATION IN THE OIL LAYER
13	ELECTRON BEAM
14	CLOSING WINDOW
15	OBJECTIVE LENS
16	ELECTRON GUN
17	CATHODE
18	SCREEN
19	VACUUM CHAMBER
20	COLOUR WHEEL

Black and White or
Sequential Colour EIDOPHOR

FIGURE 20. EIDOPHOR PRINCIPLE

The Eidophor is a large, heavy machine that is produced in black and white, field sequential color, and simultaneous color models. These projectors can produce very high brightness and thus are used for the largest display scenes. Their drawback is their size and weight, and high operating and maintenance costs.

<u>GE Light Valve</u>. Another version of the performance oil film light valve is the GE projector. Packaged as a sealed replaceable assembly instead of containing replaceable components as in the Eidophor, GE obtains full color from a single electron gun, oil control layer, and optical axis. This is done by writing simultaneously on three sets of difraction gratings which determine color intensity in conjunction with input and output spatial filters. The sealed light valve contains the electron gun, focus deflection system, fluid control layer, fluid reservoir and filter, and an ion vacuum pump. The tubes have a 2000 to 3000 hour operating life.

GE is currently developing a high line rate, high brightness version of their light valve projector which can be applied to the AAHT display. This projector will output 1000 lumens and work at 1000 scan line video rates. Expected to weigh about 130 pounds, it is light enough to be mounted on a motion platform whose motions are reasonably cyclic. With a proven and mature technology, the GE display projectors have good potential for an AAHT display.

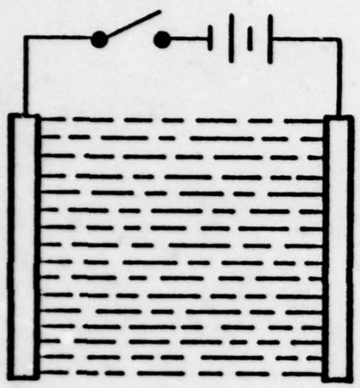
<u>Liquid Crystal Light Valve (LCLV) Video Projector</u>. Since 1970, Hughes Aircraft has been developing a projection technique using a liquid crystal light valve. Hughes has recently demonstrated a monochrome projector that has excellent promise for large screen displays and will have good reliability and low operating costs.

The liquid crystal light valve operates by tilting the

LCLV FIELD EFFECT MECHANISM

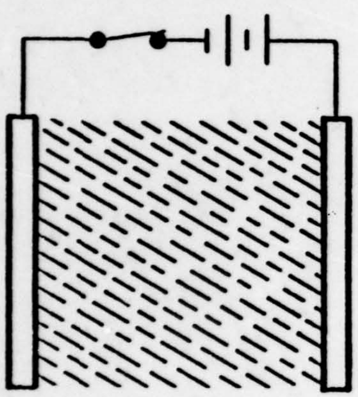
HUGHES

THE EFFECT OF ELECTRIC FIELDS



NO ELECTRIC FIELD

— MOLECULES REMAIN PERPENDICULAR



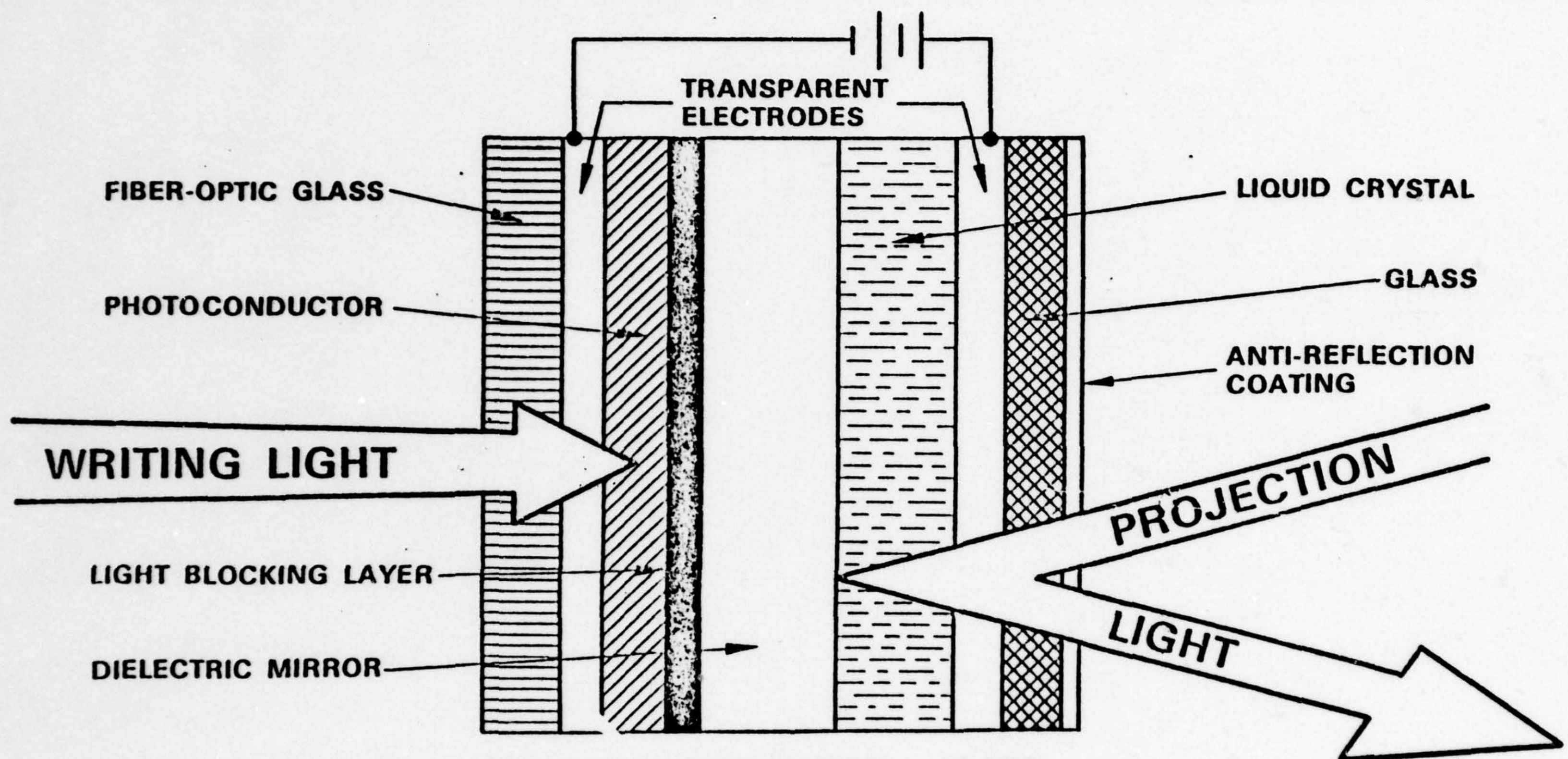
ELECTRICAL FIELD APPLIED

— MOLECULES BECOME TILTED

FIGURE 21. LCLV FIELD EFFECT MECHANISM

LCLV CELL CONSTRUCTION

HUGHES



THICKNESS: FIBER OPTICS — 12 MM
GLASS — 12 MM
LIQUID CRYSTAL — 0.006 MM

FIGURE 22. LCLV CELL CONSTRUCTION

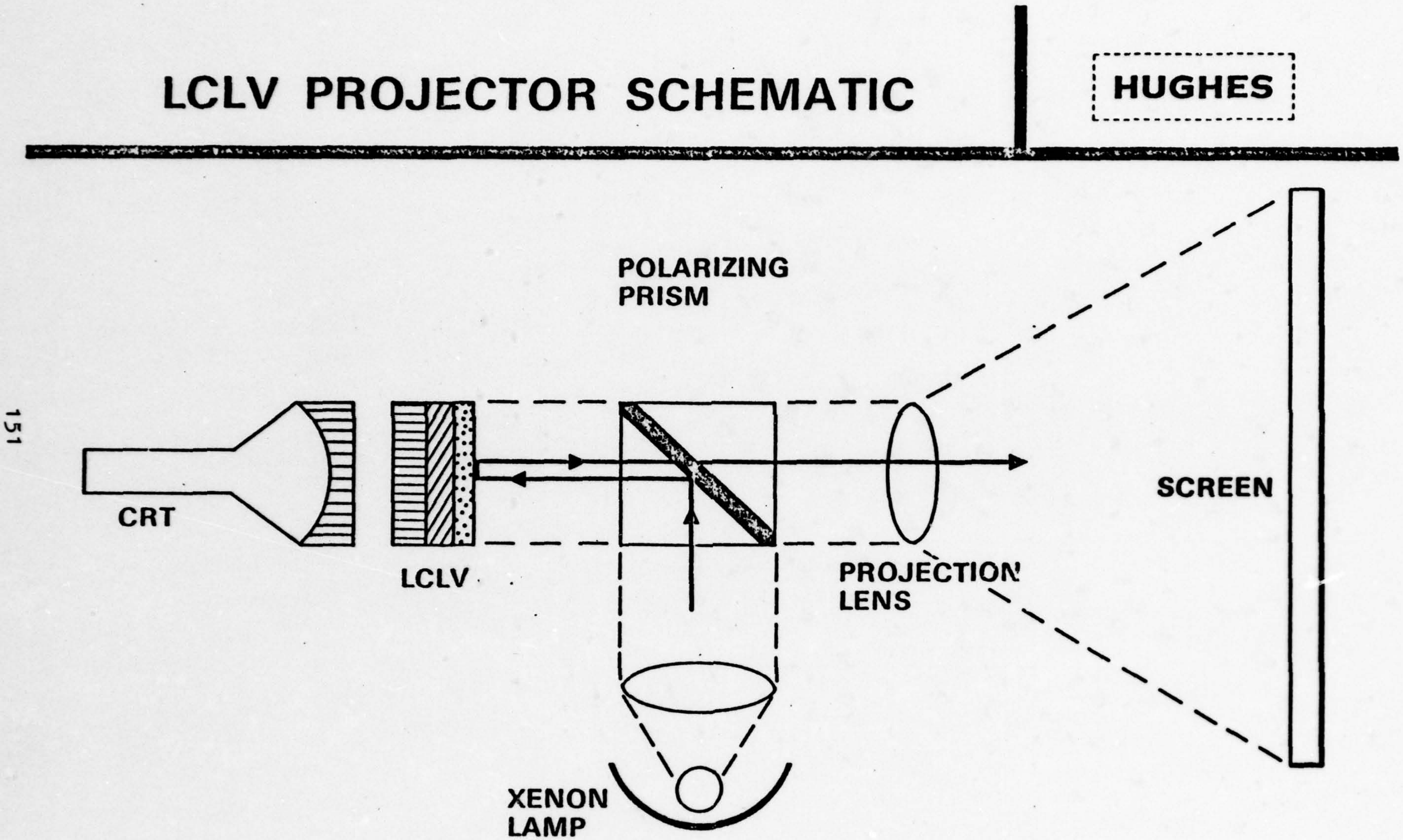


FIGURE 23. LCLV PROJECTOR SCHEMATIC

LCLV COLOR PROJECTOR FUNCTIONAL ORGANIZATION

HUGHES

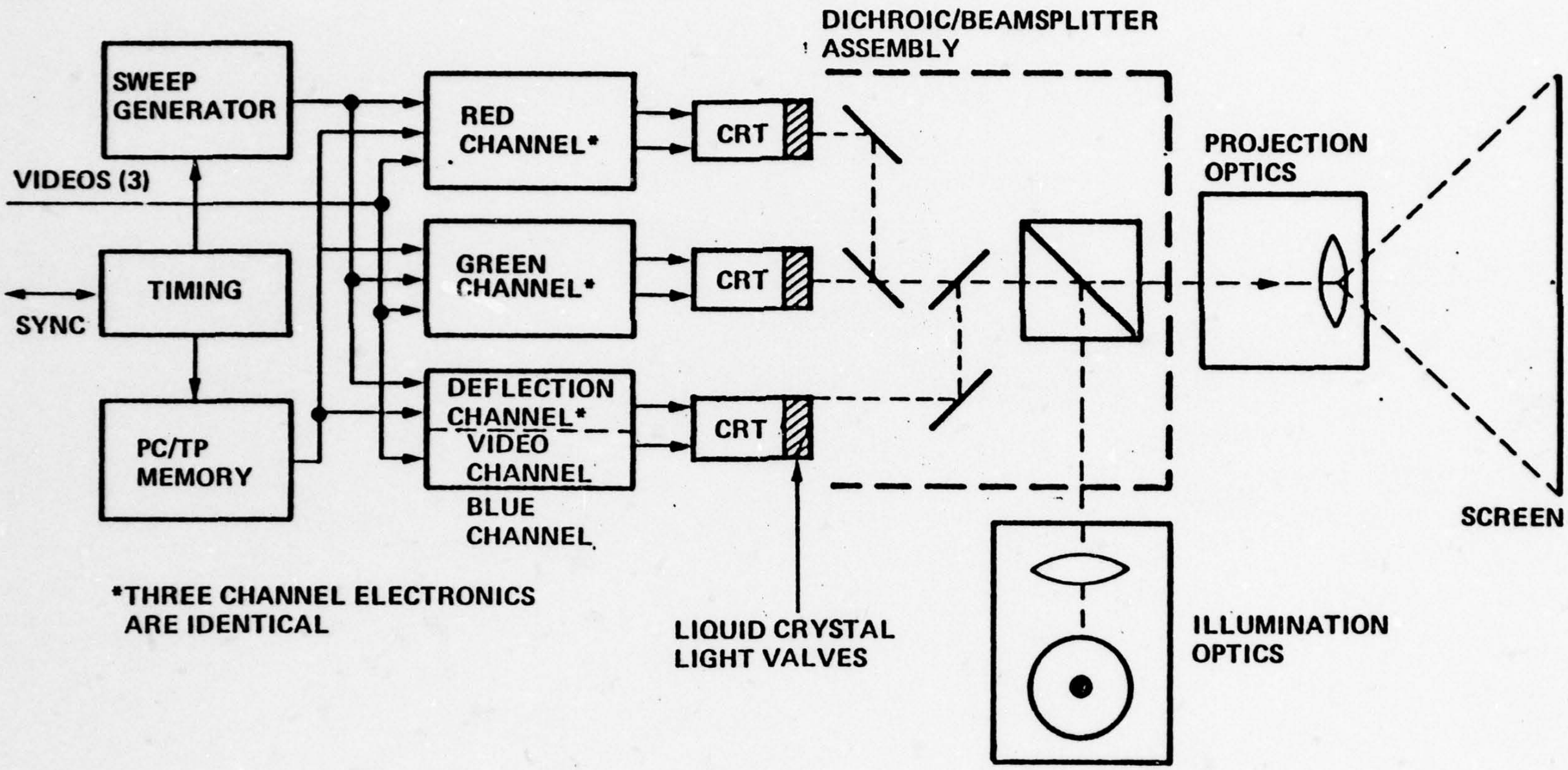


FIGURE 24. LCLV COLOR PROJECTOR FUNCTIONAL ORGANIZATION

molecules in a crystal with an electric field as shown in Figure 21. This effect is applied in a cell of sandwich construction as shown in Figure 22. A fiber optic input layer carries the writing light through a light blocking layer and a dielectric mirror to the liquid crystal. The projection light enters from the opposite side of the sandwich and is polarized by the molecules of the crystal that have been tilted by the writing light. The LCLV cell is applied in a video projector as shown in Figure 23. The writing end fiber optic input is mated to a fiber optic faceplate CRT. The high intensity light input from a xenon lamp is carried to a polarizing prism that deflects it into the projection input side of the LCLV cell. The change in polarization induced by the writing light action on the cell allows the reflected xenon lamp light to pass through the polarizing/analyzing prism to a projection lens and on a screen.

It can be seen that the components are few, simple, and fixed. The use of a CRT as the input device avoids the complexities of vacuum systems and major components that can be contaminated by oil films, as in fluid film light valve projectors. The basic concept of the LCLV is applied to a color projector by using three CRTs and LCLV cells, and combining discharges to produce a full simultaneous color display. Figure 24 shows how this is done. Since all components are static and mounted on a common base plate, a test pattern/projection distortion correction memory is included to make registration alignment easy. Once registration is done, only a component change can disturb it, and it is easily reset with the stored test pattern.

While this color projector is still in development, the potential for low cost, simplicity, high reliability and light weight coupled with resolution on the order of 1600 TV lines and outputs of 1600 lumens make it an exciting prospect. The manufacturer expects to have commercial units

available in early 1979, which is compatible with the AAHT schedule requirements.

Laser Scan Projector. In conjunction with the wide angle laser scanning image generator, NTEC is developing a compatible laser scan video projector to match the characteristics of the generator. This projector would accept the single channel, wide angle (175° azimuth) video from the generator, either a laser-scanned model board or CGI, and use it to modulate the output beams to two or more gas lasers, which would then be combined and scanned in a manner identical to the laser scanning technique for viewing the model board. The scene would be projected on a wraparound screen to be viewed.

Identical technical problems apply to the projector and the image generator. Thus, the same reasoning on its application to the AAH trainer must be followed: the technique must be demonstrated and evaluated before it can be seriously considered.

Virtual Image Displays

Mirror/Beamsplitter. The common virtual image display used in most flight simulators is of the mirror/beamsplitter type. This utilizes a curved mirror to collimate the image produced on the face of a CRT. The partially silvered beamsplitter allows the optical axis to be folded so that the observer can see the infinity-projected image on a direct axis while the CRT image is reflected 90° to the mirror. The simplicity of these displays lead to low costs, good reliability, and adequate fields of view. However, the viewing volume of the mirror is such that the proper image can be seen by only one observer. Also, with the folded optics, physical limitations are such that multiple displays cannot be mated to form a continuous image. At best, distinct gaps are left when multiple displays are abutted.

In-Line Infinity Optics. In-line infinity optics were developed to overcome the problem of mating multiple channel infinity displays to form a continuous, wide-angle scene. With this display, commonly known as the pancake window, developed by Farrand, the observer, the optical elements and the CRT are all along a single optical axis. A complex arrangement of polarizers, fresnel elements, and mirrors are used to achieve a collimated image. By arranging the periphery of the window in a pentagonal shape, multiple displays can be mated to form a continuous, wide-field image.

The major limitation, besides increased cost and optical complexity, is that extensive light losses are experienced due to the optical techniques employed. Only about 1% of the CRT faceplate brightness is transmitted. Thus, even with high output CRTs, display brightness is low, usually less than 1 foot-lambert.

The best known example of multiple pancake window display is the Advanced Simulator for Pilot Training (ASPT) at the Air Force Human Resources Laboratory at Williams Air Force Base. This system uses seven huge pancake windows driven by special 36-inch CRTs in each of two cockpits. The system produces a very wide-angle, large-elevation, monochrome display. In order for the single observer to see a continuous image, each channel must display a picture that overlaps its neighbors so that head motion across the viewing volume will not produce a blank section in one channel before that part of the picture appears in the adjacent channel.

Apropos of maintainability, it was noted during a recent visit to the facility that the pancake windows have deteriorated with time and now produce a relatively dim picture with distracting specks from dirt in the optical system.

Conclusions. The infinity projection optical quality of virtual image displays is pleasing to an observer watching a moving scene. While multi-channel wide angle displays are possible, they are costly, complex, and suited to individual observers only.

Screen Considerations

Since all video projectors display their images on a screen, consideration must be given to screen characteristics and dimensions. The geometry of the display, the image brightness on the screen, and the projector luminous output are all related. For a display which will be observed by more than one viewer, such as in the pilot/gunner trainer, a spherical screen is not suitable because of its limited viewing volume. Thus, flat or cylindrical screens should be considered.

Flat Screen. Figure 25 shows a typical flat screen arrangement with rear projection. This arrangement allows on-axis projection for minimum distortion and provides projection ratio freedom.

The major problem with rear screen projection for observers offset from the vertex of the screen axes, which is the preferred viewing location (PVL), is the significant brightness difference that occurs at the screen intersections. This is due to the high angular difference of the rays from the two screen edges to the observer's eye. This is emphasized by screen gains of higher than unity, as demonstrated by Figure 26. This shows that the brightness ratios for the three-flat-screen configuration rise well above 4:1 for screen gains of 2.5 for an observer who is 2 feet from the PVL for a screen distance of 10 feet.

Another problem with rear projection on a screen is the space requirement. In addition to the theater area for the cockpit module and screen, additional clear area behind the

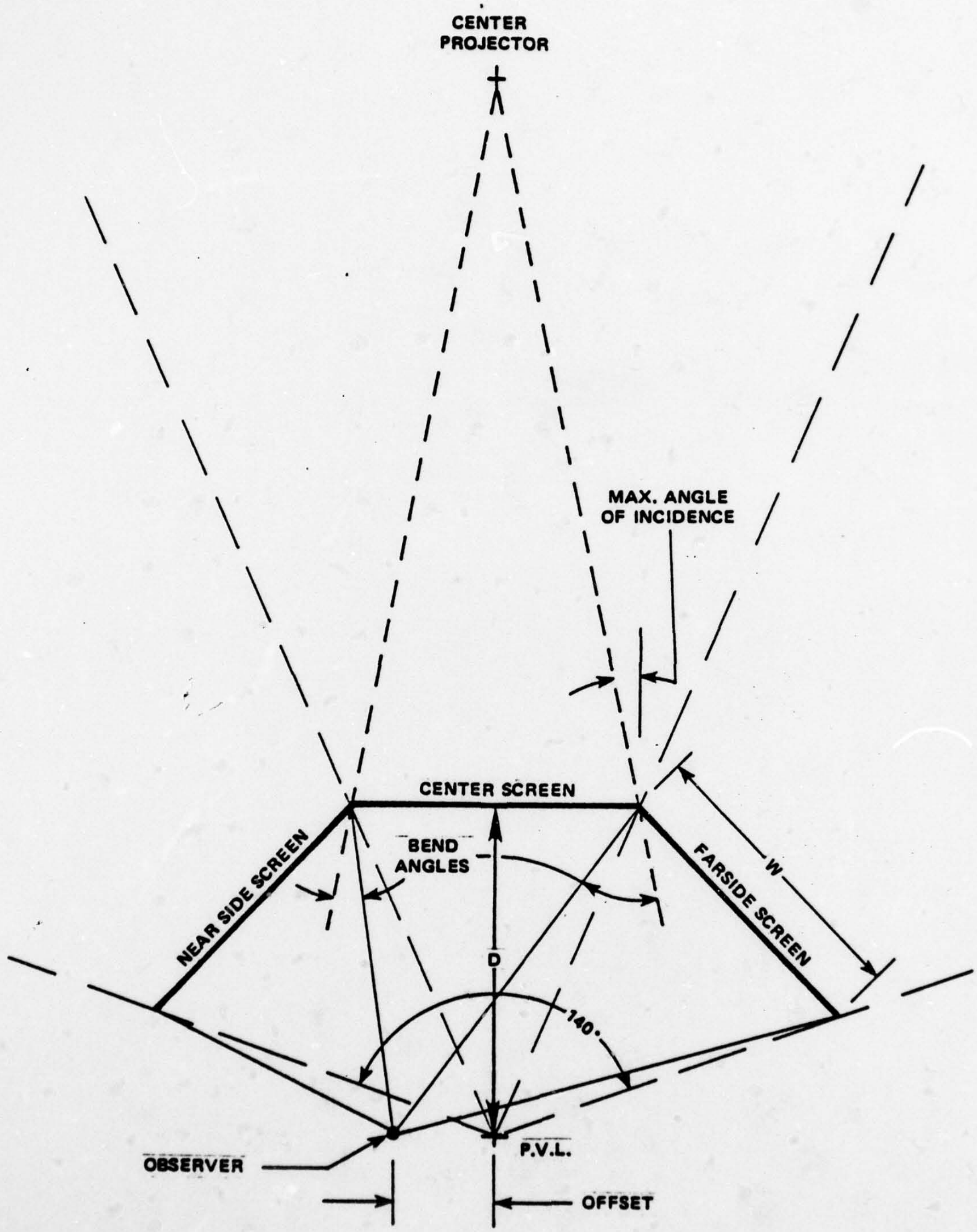


FIGURE 25. REAR PROJECTION SCREEN GEOMETRY

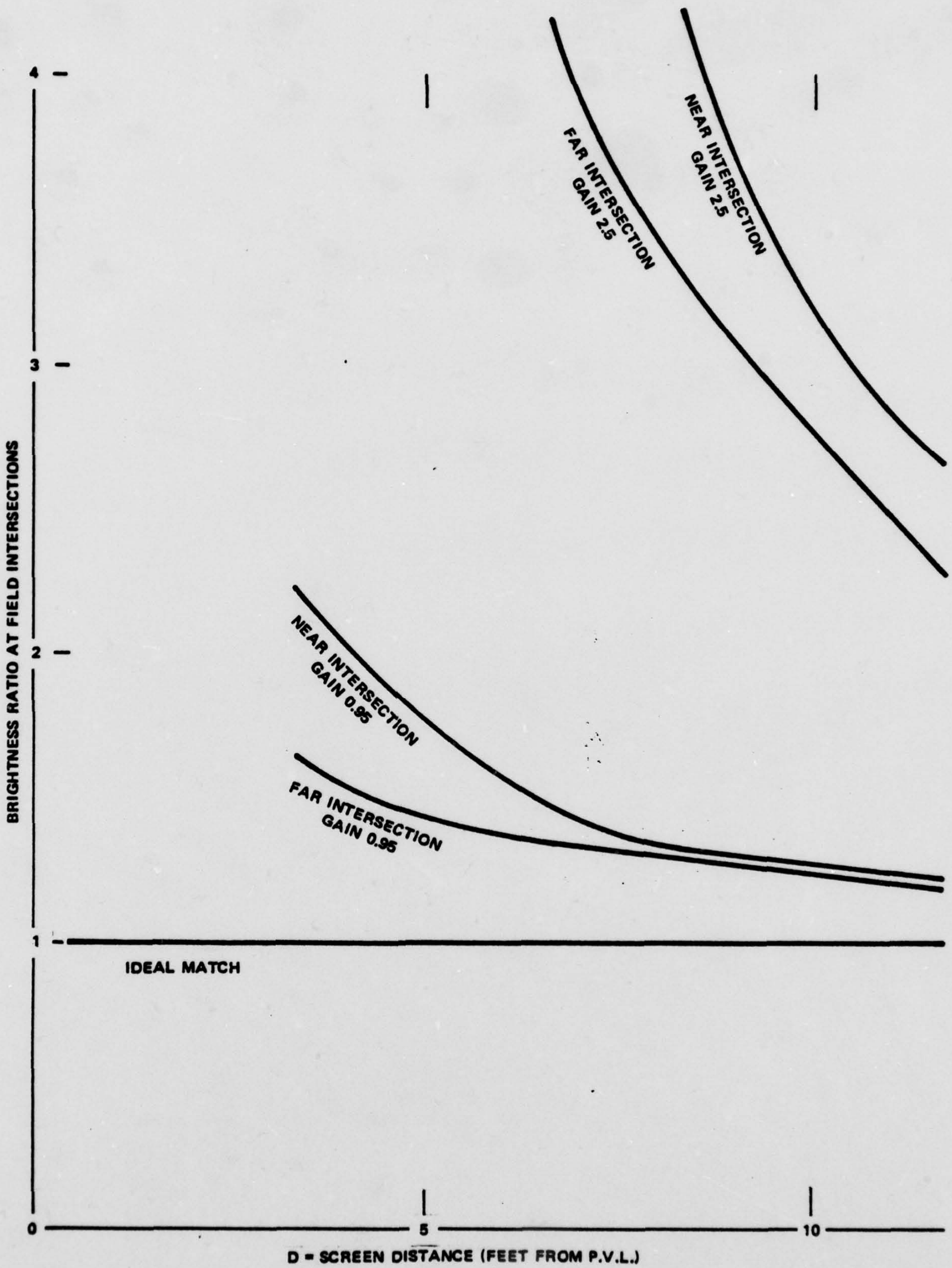


FIGURE 26. BRIGHTNESS RATIO FOR TWO-FOOT OFFSET

screen is needed to provide for projector throw distances. Figure 27 shows the relation between the projection ratio, which is the throw distance divided by picture width, and the angle of incidence to the screen edge. This relationship exacerbates the brightness ratio problem as it is reduced, and impacts the space problem as it is increased.

Cylindrical Screen. These problems, while subject to reasonable compromise under some circumstances, cause us to turn toward the cylindrical screen configuration. Front-projected cylindrical screens take up significantly less space because the observer and projectors can be near to each other. Because they cannot be co-located however, projection must be offset, either above or below the observer's location. This causes some distortions, such as keystoning and line sag, which must be corrected, but this has been done very successfully in this kind of installation. Figure 28 shows a typical cylindrical front-projected screen geometry with the same basics as the flat screen configuration for similar offsets. Figure 29 shows that the brightness ratio problem for adjacent scenes is very low for screen gains of the type being considered.

For a cylindrical configuration, Figure 30 presents a typical tradeoff curve set for various angular dimensions per projector channel. The illustration relates the screen distance from the preferred viewing location to the projector output required to obtain a picture of specific brightness. The curve is drawn for a screen gain of two. Screen brightness is simply equal to projector output per square foot of screen area, multiplied by screen gain. The curve shows, for example, that at a screen radius of 20 feet and picture dimensions of 40 x 30 degrees (width/height), 73 lumens of projector output are required for each foot-lambert of picture brightness. Thus, for a 5 foot-lambert picture, a projector capable of at least 365 lumens output is required.

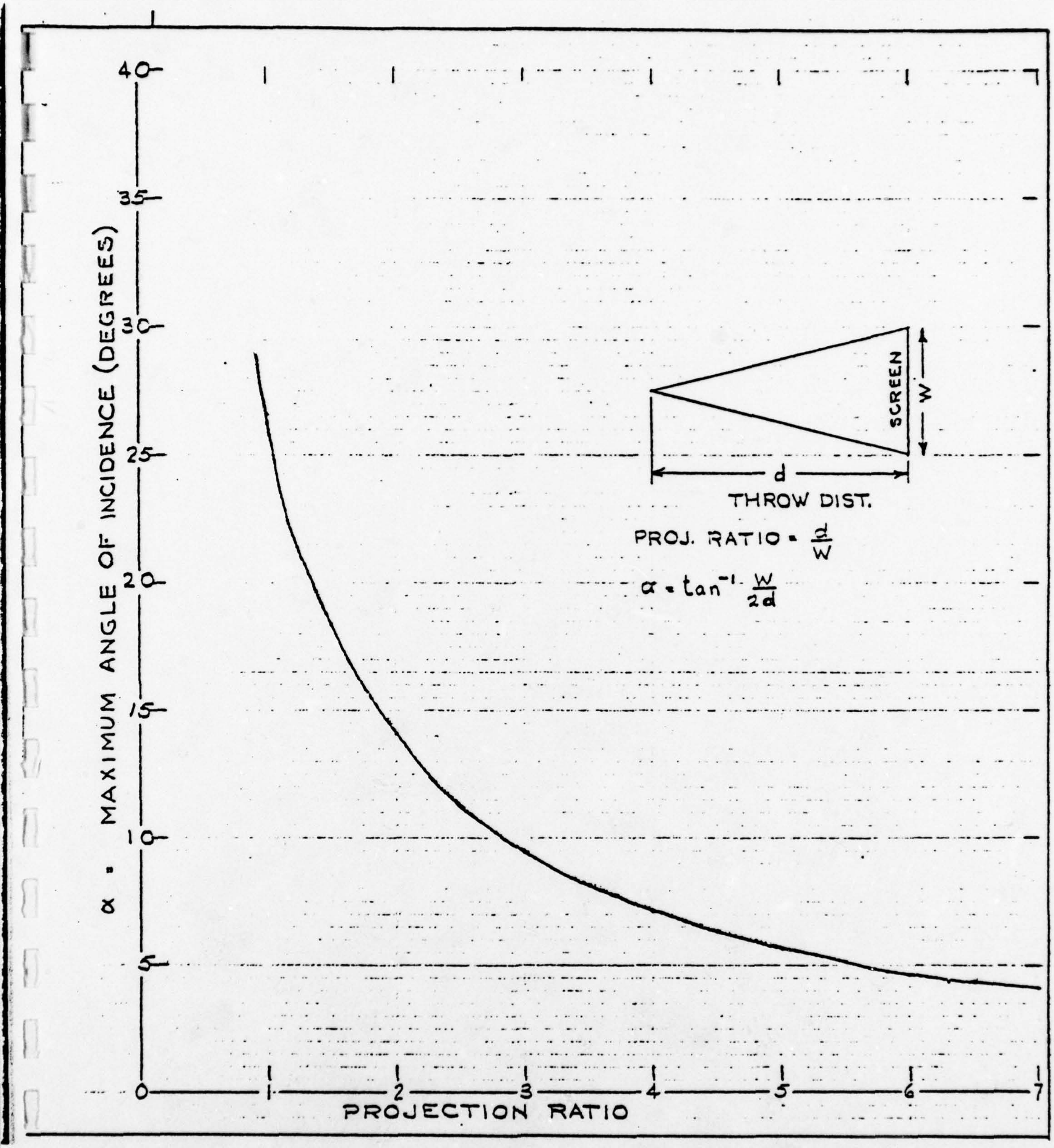


FIGURE 27. PROJECTION RATIO vs ANGLE OF INCIDENCE

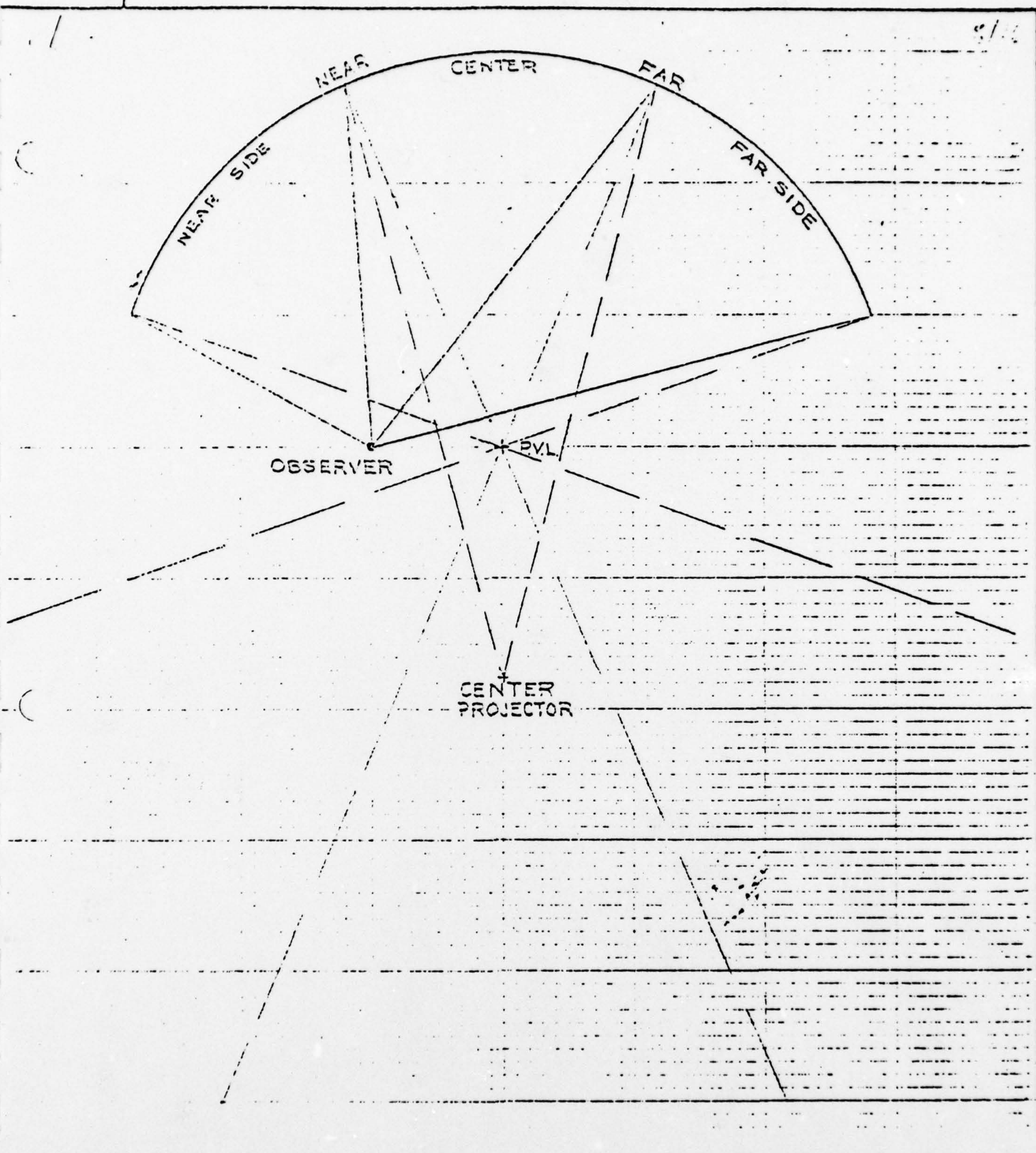


FIGURE 28. FRONT PROJECTION SCREEN GEOMETRY

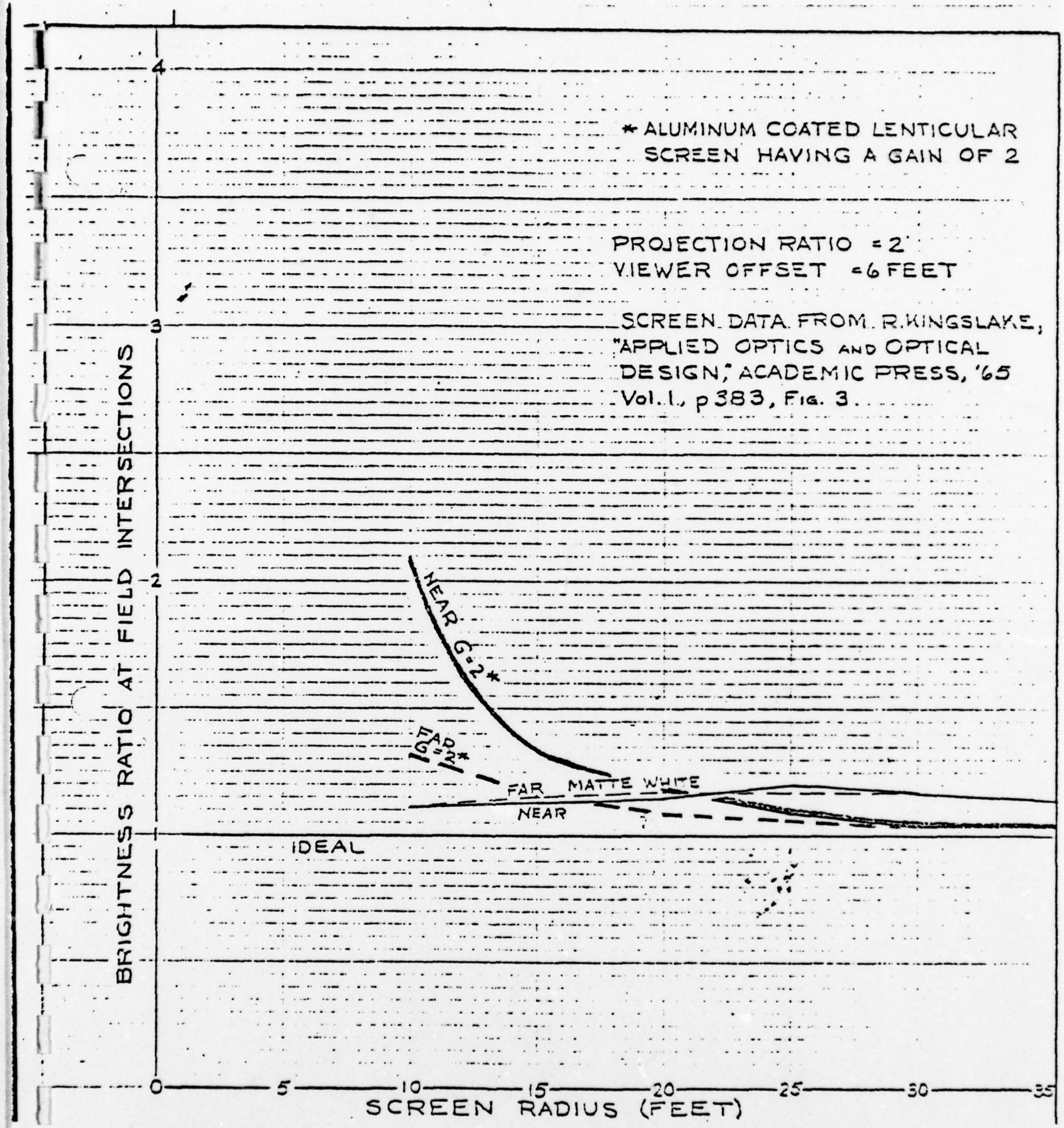


FIGURE 29. BRIGHTNESS RATIO vs SCREEN RADIUS

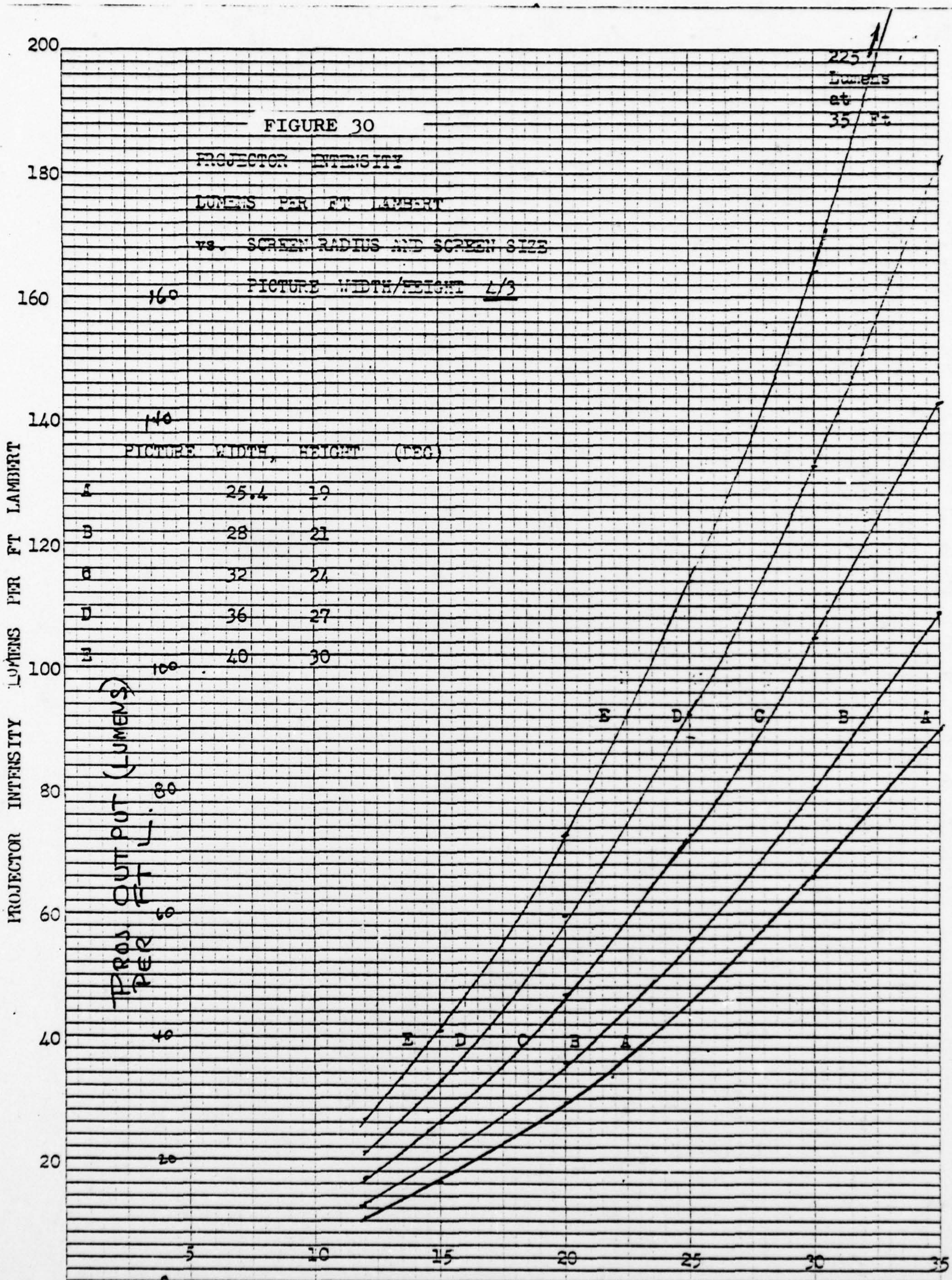


FIGURE 30
PROJECTOR INTENSITY
LUMENS PER FT LAMBERT
vs. SCREEN RADIUS AND SCREEN SIZE
PICTURE WIDTH/HEIGHT 4/3
PICTURE WIDTH, HEIGHT (DEG)
A 25.4 19
B 28 21
C 32 24
D 36 27
E 40 30
225 Lumens at 35 Ft
PROJECTOR INTENSITY LUMENS PER FT LAMBERT
PROJ OUTPUT (LUMENS) PER FT L.
SCREEN RADIUS (FT)
E D C B A
E D C B A
200
180
160
140
120
100
80
60
40
20
0
5
10
15
20
25
30
35

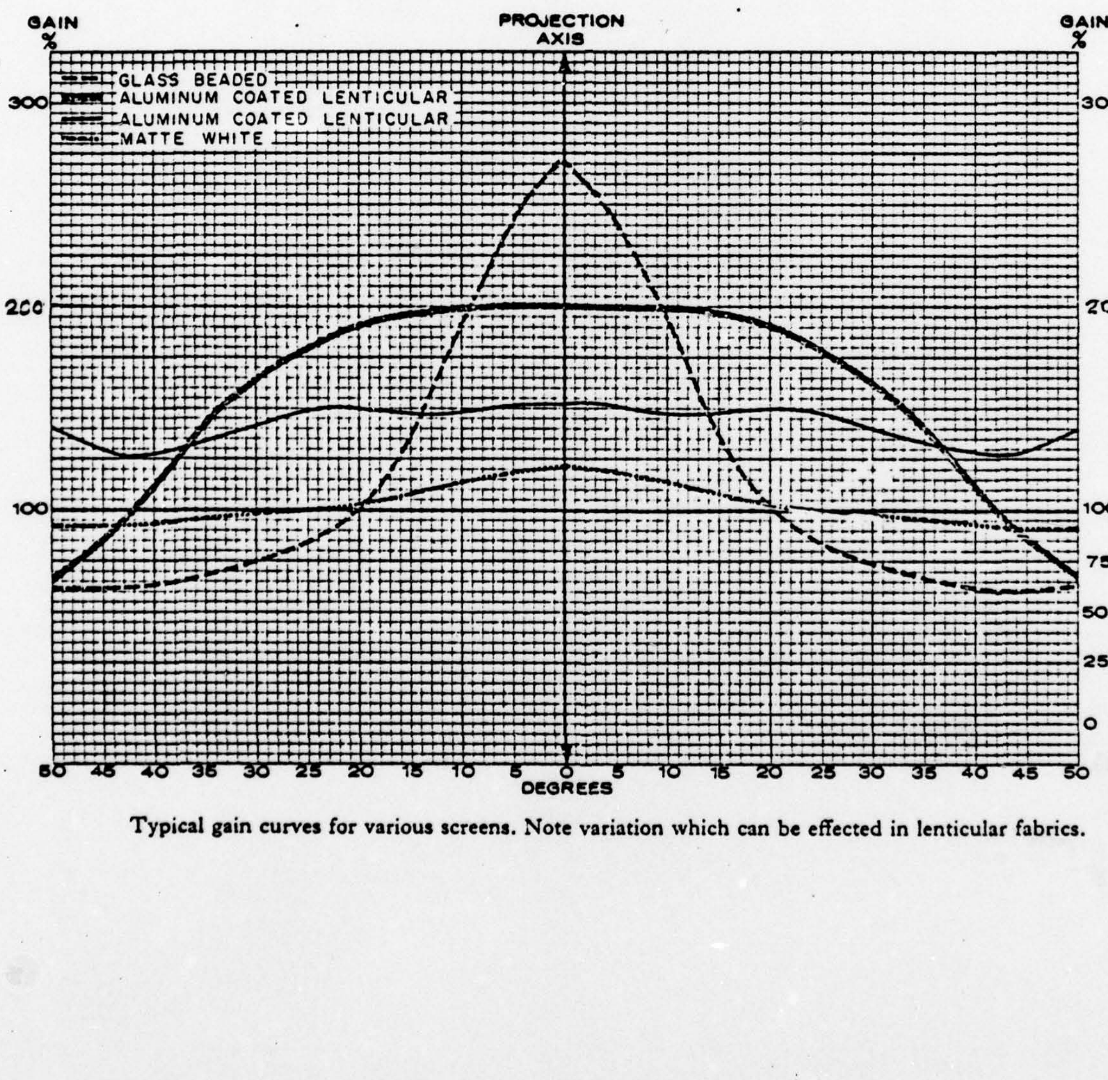
If the screen radius is reduced to 15 feet, only 200 lumens would be required. Or, it can be seen that for a 1000 lumen projector, a screen as large as 32 feet in radius will still give a 5 foot-lambert picture.

Screen gain is another variable which must be considered. The ideal is to use a unity gain screen because no brightness variation occurs regardless of projector to observer angles. However, if the observers are relatively fixed, as in the pilot/gunner trainer, it is much more efficient to use screen gain and lower the projector output brightness and input power requirements. Figure 31 shows the gain curves for a number of typical screens that could be considered for various observer angles to the screen projection axis.

The tradeoffs for the display geometry, video projectors, screen gain and size, and cockpit and motion modules are quite sensitive, and have a major impact on the final trainer configuration.

Conclusions and Recommendations Regarding Image Displays

Sperry SECOR's conclusions are that real-image displays should be the choice for the AAHT visual modules. The virtual image methods reviewed (the mirror/beam splitter or the pancake window type) are, respectively, either incompatible with wide field continuous images or are too optically complex and costly. Furthermore, virtual image displays are oriented to a single observer and the viewing volume of a single display cannot be expanded to include both the pilot and gunner in a tandem cockpit. Multiple virtual image displays oriented for each crewman are too voluminous to retain a single cockpit configuration for the pilot/gunner trainer.



Typical gain curves for various screens. Note variation which can be effected in lenticular fabrics.

FIGURE 31. TYPICAL GAIN CURVES

Recommended Approach to Pilot/Gunner Trainer Visual Module

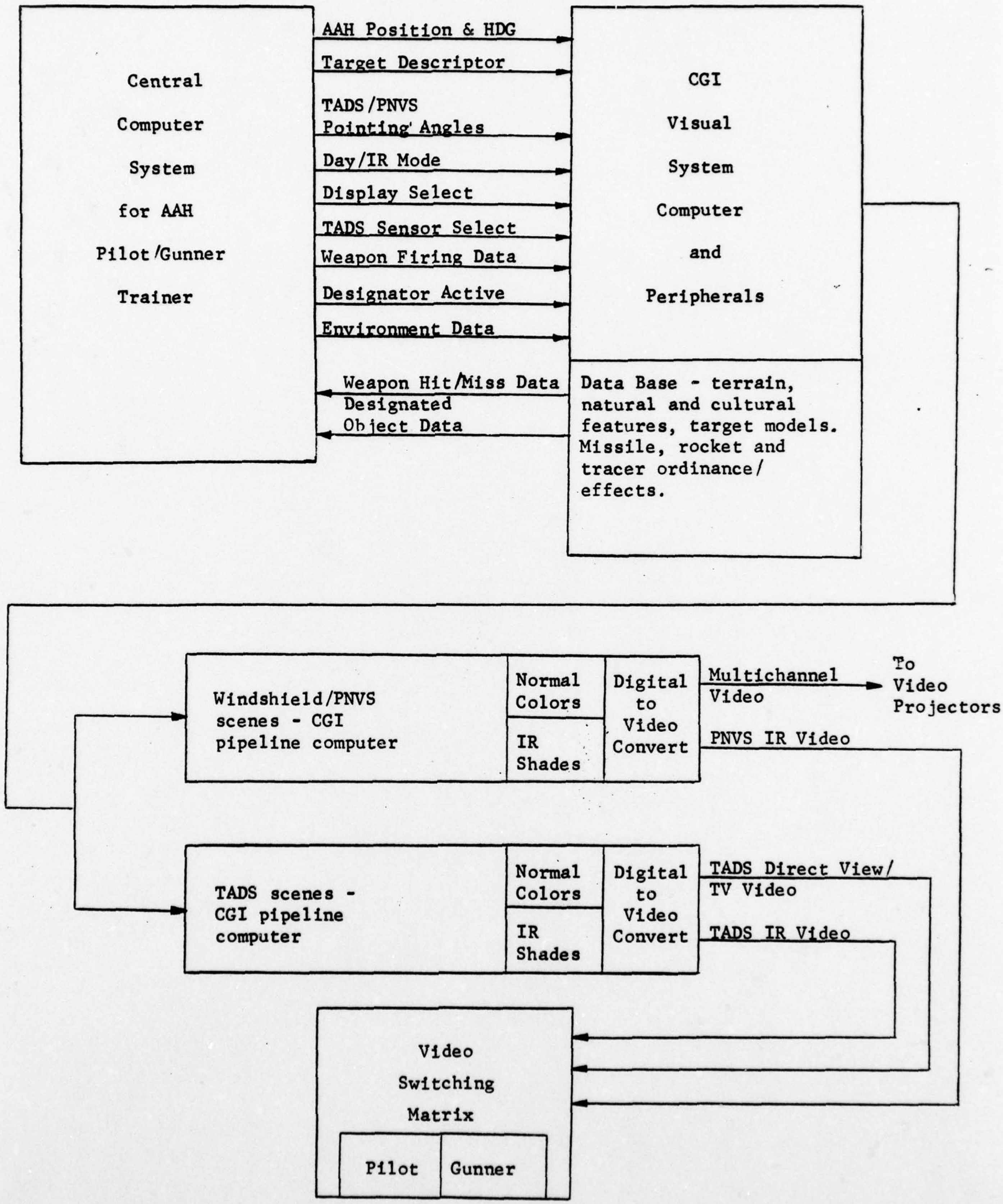
The following is a description of the visual module that is recommended for the AH-64 FWS. This system derives from the preceding analysis of image generation and display technology, and meets the study objectives of requiring engineering rather than experimental effort, using in-hand technology, using the best technical approaches, and being cost-effective.

The recommended pilot/gunner trainer (the Mission Trainer) visual module is composed of a computer-generated image system, driving both liquid crystal video projectors and simulated aircraft visionics equipments. The projectors display scenes on a cylindrical wraparound screen. Details of the visionics equipments are discussed elsewhere in this study report. Figure 32 is a block diagram of the pilot/gunner visual module concept.

Image Generator. The image generator is composed of a host computer driving two special-purpose CGI pipeline processors. The two channels are required because of the need for TADS displays simultaneous with the wide field-of-view wind screen display.

The AAHT central simulation computer has full control of the visual module. Essentially, all inputs to the visual module, whether originated in the instructor's station, the motion system or the cockpit module, are processed by the computer module. Figure 33 shows the functional flow of the CGI system.

The host computer contains the data base, which comprises a digital representation of the gaming area in the form of vertices of closed polygons. This includes all terrain, static natural and cultural objects, all moving objects, own and other's weapons effects, and scene lights. The primary job of the host computer is to manage the data base so that



Block Diagram of Visual Module for Pilot/Gunner Trainer

Figure 32

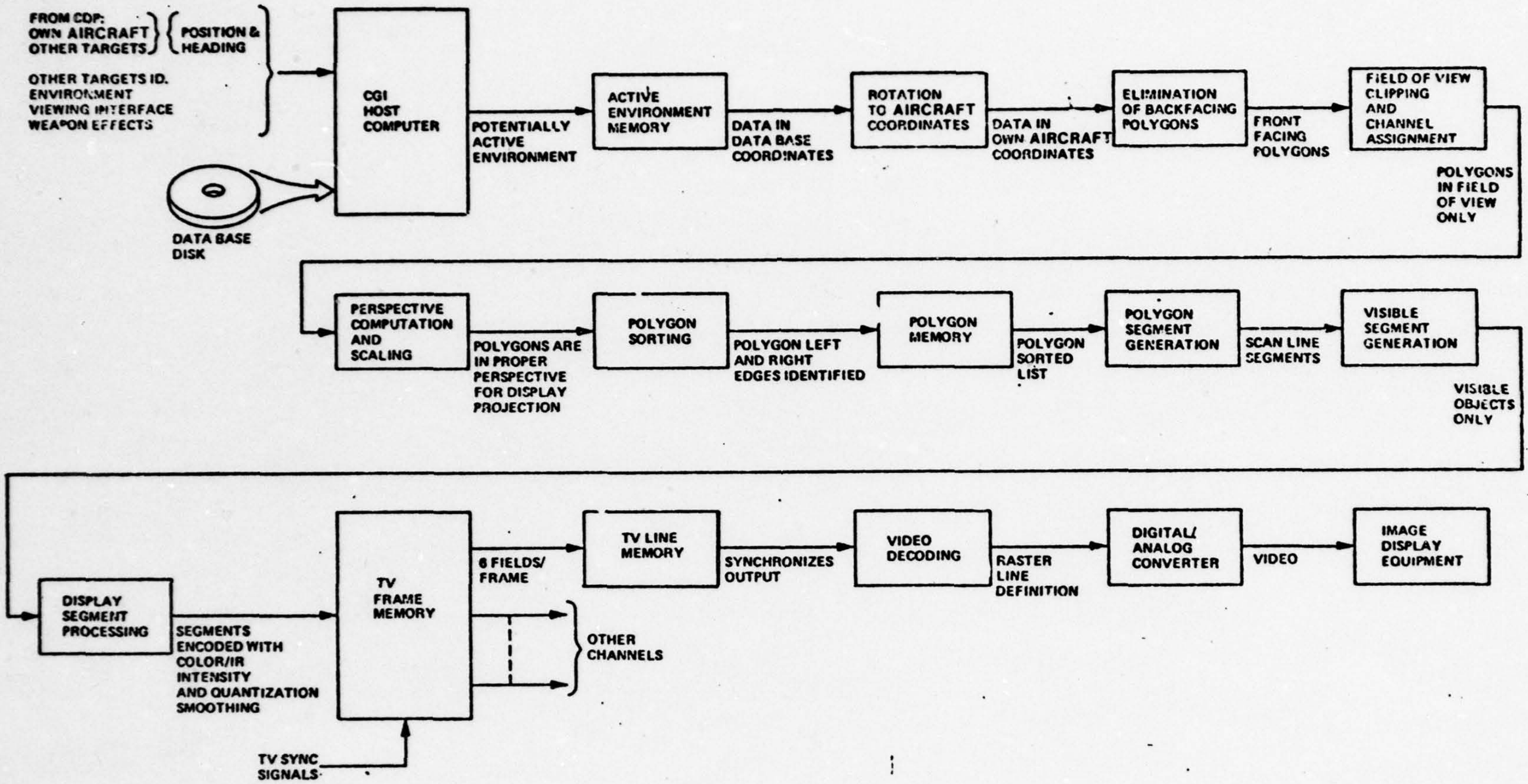


Figure 33. Typical CGI Channel Block Diagram

it can call up from the storage disk that part of the gaming area visible from the helicopter's present position. This static data is held in a special memory, together with data on any selected moving objects or weapons effects, where it is acted upon by the special purpose CGI pipeline processors.

From the active environment memory the polygons composing the static and moving scene objects are rotated from a data base storage-coordinate system to an own-aircraft coordinate system. This allows elimination of all backfaces because these polygons are not visible to the viewer.

All front-facing polygons are now passed down the pipeline to the next stage, where the field is clipped. Here all objects outside the final field of view are eliminated, either because they are too distant or above or below the final displayed scene. At this stage, channel assignments for multi-channel display are designated.

Passing down the pipeline, scaling computations are performed so that each polygon is displayed in proper perspective for projection on a flat screen. Also, each edge is provided with edge slope information.

This is followed by a polygon sorting process, where the edges of each polygon are identified as either a left edge or a right edge. Also in the polygon sorting unit, the uppermost vertex for each polygon is found and used to order all polygons in the scene vertically and horizontally for each channel. The sorted list of polygons is stored temporarily in a polygon buffer memory.

The output of the polygon buffer memory is fed to a polygon segment generator, which acts as a scan converter. The edge slope information previously calculated is transformed to scan line intercept information. Each edge type polygon is converted to scan line segments bounded by the left and right polygon edges. The polygon segment generator

creates a sorted list of all polygon segments, ordered by the left edge scan intercept of all polygon segments on a scan line. This ordered list is sent to the visible segment generator.

The purpose of the visible segment generator is to eliminate segments or parts of segments hidden by other segments. This is accomplished by comparing range data wherever a condition of overlapping polygon segments exists along a scan line. That portion of a polygon segment more distant than another is discarded.

The segments, now only representing objects known to be visible, are sent to the display segment processor. For each segment received, the data is reformatted and anti-rastering segments are created. The reformatting of the data is necessary to introduce fog and color information for daylight operations, or IR intensity for IR simulation. Anti-rastering or edge smoothing is introduced to reduce digital quantizing effects.

The output of the display segment processor is fed to a dual TV frame memory. Here the information is stored in a dual buffer and is read out of each buffer, one frame at a time, at a synchronized rate of 30 times/second.

The simulation computer processes the data for own helicopter and other moving objects 30 times/second. The CGI pipelines perform their computations asynchronously, but within the 1/30th second period. Thus, data for a new picture is passed to the frame memory 30 times/second. From that memory, at synchronized video rates, each TV line is read out, decoded, converted to analog video and sent to its display device. The CGI processor that drives the liquid crystal display projectors has an individual TV line memory, decoder and D/A converter for each projector.

The processor driving the TADS displays provides the

direct view or day TV video to all the display devices that can view those displays.

During night operations, when the pilot is using the PNVS, and the gunner the FLIR sensor in the TADS, each processor section is converted to insert IR intensities instead of color, and the video line that had been driving the center projector drives the PNVS display (IHADSS), while the other projectors are blanked.

CGI Data Base

The data base contains the digital data representing the models and spatial relationships of all visible objects in the gaming area. Preparing the data base involves conversion of map, topographic and model data to compatible digital form for the CGI host computer.

The starting point for terrain data for an actual location (which is probably preferable to a fabricated data base) is the Defense Mapping Agency data. This must be supplemented by photos, topographic maps, special maps for unique areas and drawings for objects requiring specific details. Cultural features such as bridges and buildings are based on photos or drawings.

Representations of the same areas under IR conditions may be taken from data for such conditions which should be available from the Night Vision Laboratories facilities at Ft. Belvoir, Virginia. All this data must be modeled in polygon format representations. Conversion to digital form is done on a digitizer tablet, and conversion programs collate and compile the digitized data into a single origin Mercator projection map in digital data base form for use by the CGI visual system.

Similarly, drawings and photographs of typical target vehicles, friendly aircraft, and weapon effects are modeled

and stored to be called up for display by object selection codes in training scenario programs or by the instructor.

Module Integration

The simulation computer uses inputs from the instructor, the cockpit module, and the motion system, together with the initial conditions, to compute the position of own helicopter and all other moving objects which are the primary inputs to visual module. Table 7 shows the specific inputs to the visual module that are required from the central data processor.

In addition to the positions of the helicopter and moving objects, the simulation computer can control the environment by setting visibility range, which mixes haze into the scene, from unlimited to zero visibility; setting the light level from full daylight to night; controlling sunlight direction; cultural or vehicle lights on/off; and, with variable color coding of the data base, set seasonal features such as snow and vegetation colors. Most of these factors are under direct control of the instructor, who can also select and control moving targets, or he can call up a software scenario to arrange and maneuver a particular threat array. The visual system data base also stores and inserts weapon effects on computer command. Tracer paths or rocket trails are simulated. On helicopter missile release, the flash and smoke are seen, and the tail plume and missile are seen following the path directed by the simulation computer, to the strike on target or miss. The blast effect at impact is also shown and a hit removes the target object from the scene. The visual weapon effects from other vehicles can also be commanded through the simulation computer by the instructor. Firing flash, tracers and smoke or dust are included.

The data on crew-selected conditions of the TADS and PNVS

TABLE 7. INPUTS FROM SIMULATION COMPUTER

FUNCTION	INPUTS	
Own Aircraft (Dead Reckoning)	$\bar{X}$, $\dot{X}$	X position and direction cosines
	$\bar{Y}$, $\dot{Y}$	Y position and direction cosines
	$\bar{Z}$, $\dot{Z}$	Z position and direction cosines
	H	Heading
Other Position Orders	Xc, $\dot{X}$c	X position and direction cosines
	Yc, Yc	Y position and direction cosines
	Hc	Heading
	c	Identification of type
	Ac	Altitude (if aircraft)
Environment	Visibility Ambient Light Direction of Illumination Scene Lights Fog Bank Seasonal Effects; Snow, Vegetation Seasonal Changes, etc.	
Own Weapon Effects & Simulation Orders	Tracers Rocket Trail Hellfire Missile Plume Smoke Flash Point of Strike	
Other Weapon Effects Orders	Tracers Firing Flash Smoke/Dust	
TADS/PNVS Data	TADS Turret Pointing Angles Direct View/Day TV/FLIR Magnification Setting PNVS Turret Pointing Angles Designator Active	

must be provided to the visual module by the central computer. The data on the turret pointing angles and selected magnification cause the TADS CGI pipeline to select the proper part of the visual scene stored in the active memory to be processed for visionics display. IR operation for TADS and PNVS is similar and has been previously reviewed.

Operation of the laser designator is simulated and integrated with weapon hit/miss computations and effectiveness evaluation. Figure 34 describes the basic function. A sensor is mounted in the simulated TADS eyepiece display which is activated by the designator control. It acts as a light pen on the video display in that it identifies the TV line and line location designated. The CGI system researches its data base to identify what object occupies that location and can compute its range and direction from the AAH. That data, combined with ballistic/missile hit probability data can be used by the CDP to calculate miss distance of weapons on targets to be used for evaluation of mission effectiveness.

Display System. The recommended screen wind display for the pilot/gunner trainer is a real image projected on a wraparound screen. The real image display offers the economies of common viewing so that both crew members can share the same display system, and realism of parallax effects, including continuity as the viewers look through different windows or move their heads. On the other hand, the real image display system shows only one viewpoint, selected as a compromise between gunner and pilot eye positions, although perhaps it might be worthwhile to weight it toward the pilot's position.

Figures 35 and 36 show a plan view and vertical section of the recommended display geometry. The screen covers 180° in azimuth. Five display projectors are disposed below the

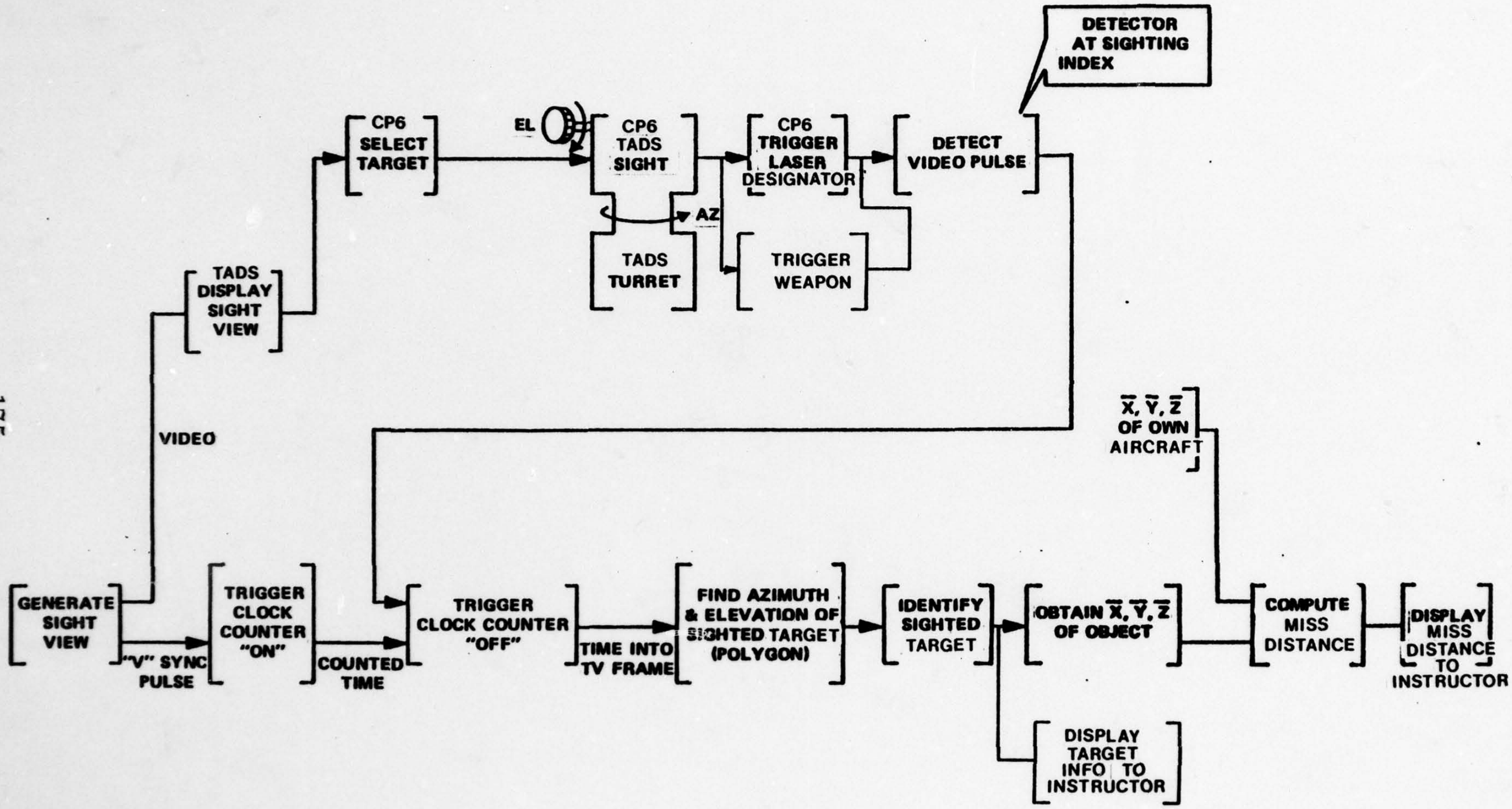


Figure 34. Miss Distance Sensing & Computation Function

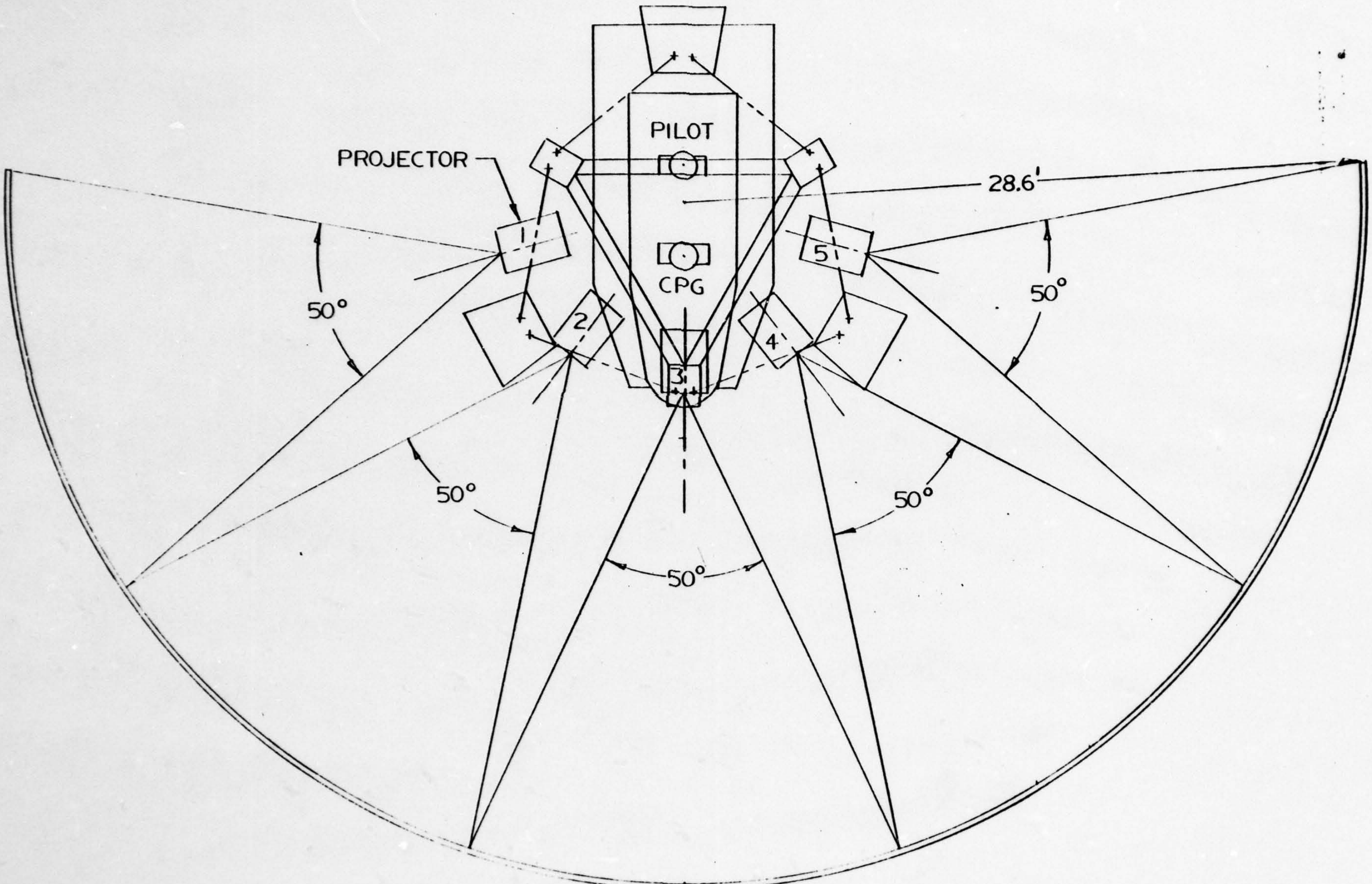


FIGURE 35. PILOT/GUNNER TRAINER DISPLAY SYSTEM PLAN VIEW

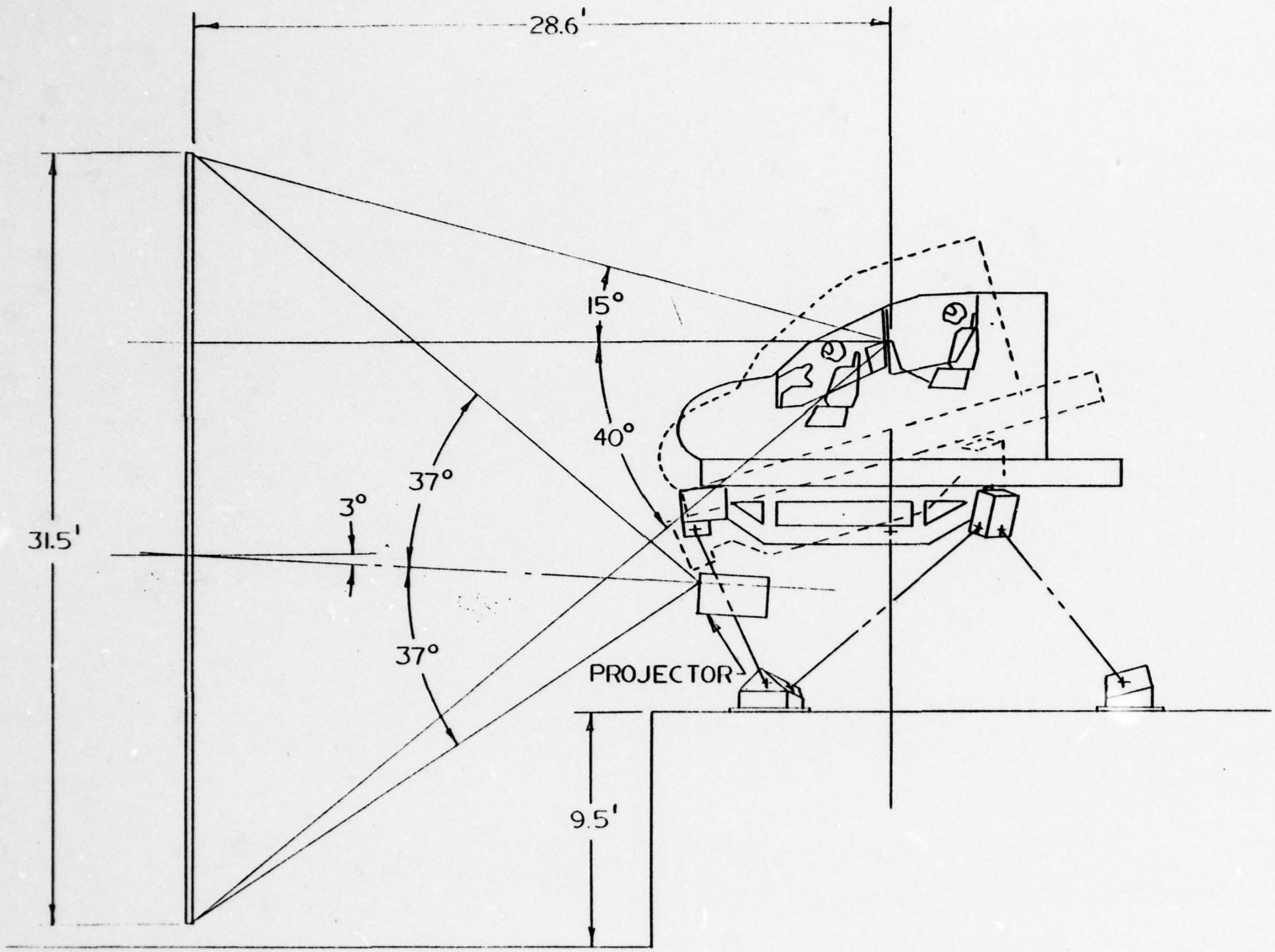


FIGURE 36. PILOT/GUNNER TRAINER DISPLAY SYSTEM VERTICAL SECTION

cockpit module and ahead of the screen origin, and each project a matched 36° azimuth scene for a 180° continuous display. The projectors have anamorphic lenses to convert their standard 3 x 4 format to about a 3 x 2 format, providing an elevation angle of 55° total, arranged to reasonably match the elevation field of view requirements discussed at the beginning of this section. Thus, 15° appears above the horizon and 40° below. This will provide the pilot with enough viewing-angle freedom for terrain flights, including NOE. The azimuth field of 180° is also a good compromise between width of field, number of projectors and display resolution. The origin of the screen is on the line connecting the pilot's and gunner's eyes, equidistant from each. This gives a small parallax error for each crewman varying with bearing angle, as shown in Figure 37. While this error is not correctable in the display, it varies smoothly from 0° for objects directly ahead to about 7° for objects directly abeam. Despite the parallax, objects always retain proper relationships, and experience has shown good user acceptance of scenes with substantially greater parallax than those shown here. The pilot and gunner are also separated vertically but the distance from the screen origin is only 0.75 feet. This gives an additional small parallax error for each man of about 2° for objects on the horizon, which decreases to zero for about 20° below the horizon.

Each section of screen is about 280 sq. ft. in area. For a screen gain of about 2, the resulting screen brightness is about 7 ft. lamberts per 1,000 lumens from the projector, quite adequate for a simulator visual daylight display. Brightness of the displayed scene varies as the inverse square of the screen radius, and directly with projector output. Brighter scenes could be obtained with a smaller screen radius of say, 15 feet, but parallax errors would grow

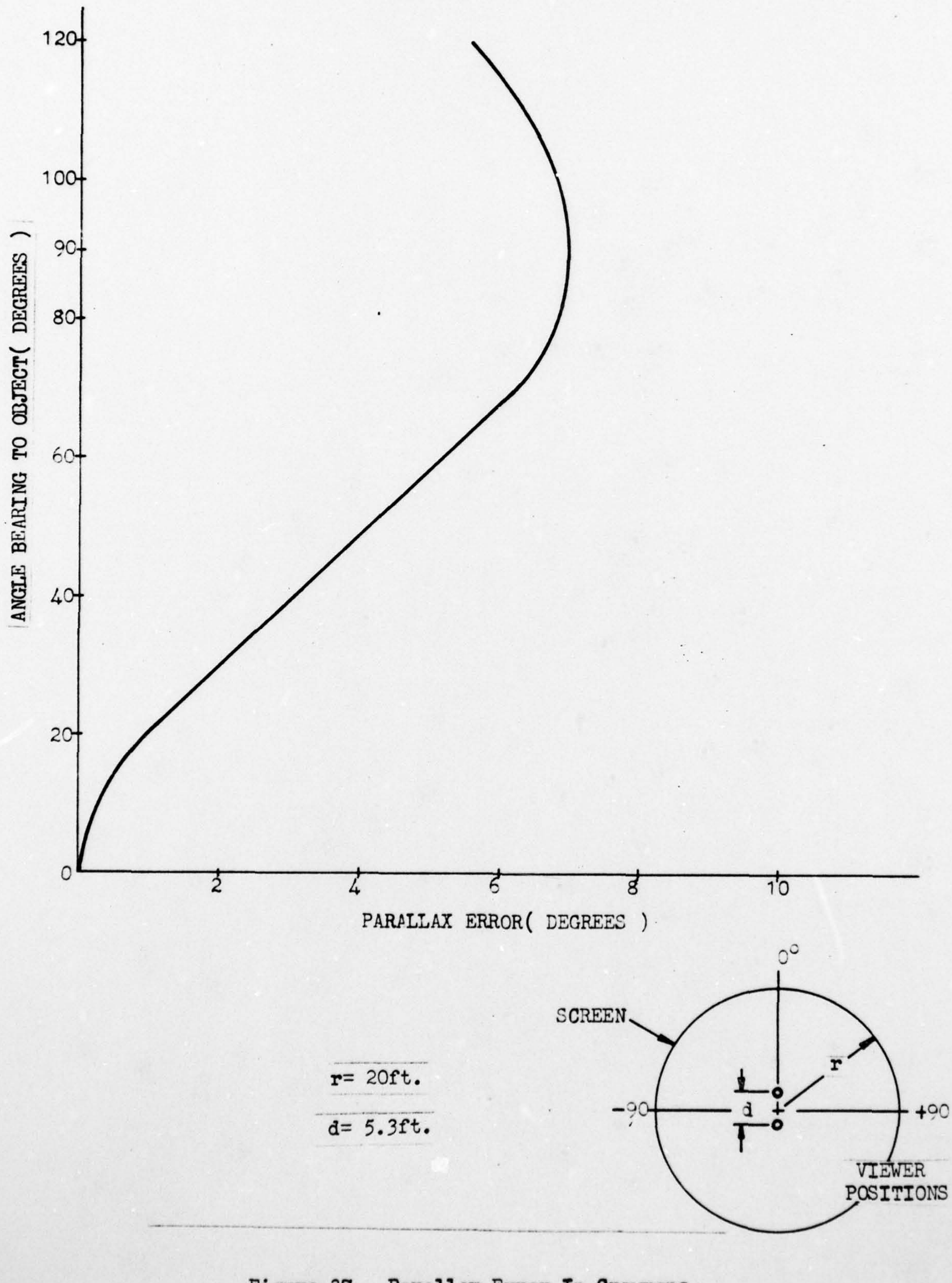


Figure 37. Parallax Error In Crewmans View of 20ft. Radius Screen

and the binocular distance cues would increase, which might have negative psychological error on the crew in observing rapidly moving objects.

Each projector's scene is matched and abutted to its neighbors to form a continuous 180° azimuth scene. This has already been successfully done by Sperry in a maritime research simulator and the techniques are now well in hand.

The CGI and projectors operate at 875 TV line standards per RS343. With the image generator providing 550 horizontal picture elements across each TV line, the resolution of the display is about equal in the horizontal and vertical directions, being about 4 arc-minutes limiting resolution.

The LCLV color projectors are expected to be of reasonable size and weight. They are mounted below the cockpit module on a fixed platform. A sketch of the projector is included as Figure 38. The five-projector array must be mounted so that the legs of the motion system and the base of the cockpit module do not interfere with the projection. Minor corrections for line sag and keystoning can be made optically and electronically, giving the operator fine control and distortion-free visuals.

LIQUID CRYSTAL DISPLAY HDP-2000

HUGHES

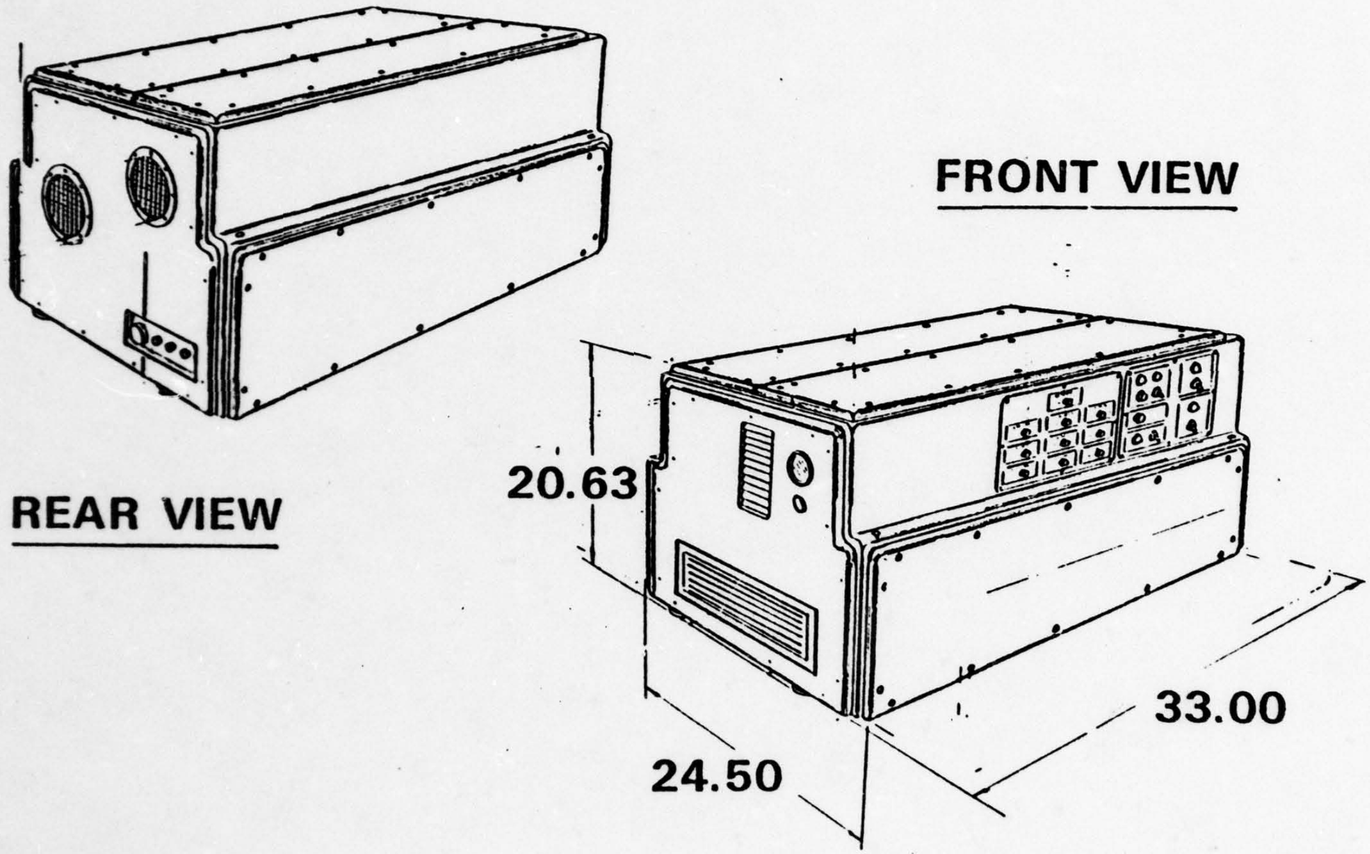


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FIGURE 38. LIQUID CRYSTAL DISPLAY HDP-2000

COMPUTER SYSTEM MODULE

This portion of the study report addresses the items listed in the Computer Section Study Outline contained in Attachment 4 to the contract. The order of investigation was somewhat different from that contained in Attachment 4, as explained in the following.

Computer System Evaluation Process

The computer system evaluation process was composed of five phases. The first phase was a data-gathering phase, applicable to all four of the remaining phases. Data gathering included compilation of published data, informal interviews with simulator users, interviews with cognizant Sperry SECOR personnel and interviews with computer vendor personnel.

The second phase was the evaluation of certain design considerations in the areas of:

1. Use of FORTRAN IV (as opposed to assembly language).
2. Use of computer manufacturer's operating system as a real-time executive.
3. Use of real-time on-line diagnostics (as opposed to off-line diagnostics).
4. Use of MOS memory (as opposed to core).

These considerations were evaluated, and conclusions reached in order to proceed with phase three, establishment of the computer system criteria. Computer system criteria were divided into two types, pass/fail criteria and quantitative/qualitative criteria.

The fourth phase was to investigate the available computer systems to determine if they met or exceeded the criteria established in phase four. Any computer system

which did not meet the pass/fail criteria was immediately eliminated from consideration. The computer systems were then measured against the established quantitative/qualitative criteria. The first step in the measurement process was to determine the instruction throughput of the computers under consideration. To do this, the first step was to determine the overall instruction mix by analyzing the implementation methods, the languages used, and the extent of their use for each program module. Second, the products of the fractional usage for each instruction class and the instruction class execution time of the candidate computer were calculated. The summation of these products yielded the average execution time of a single instruction in microseconds. The inverse of this execution time yielded the average execution speed, or the instruction throughput of the computer under consideration. Measurement of the candidate computers against the remaining criteria was a straight-forward process. In addition to the qualitative-quantitative criteria, such factors as cost and configurability were also analyzed for each of the candidate computer systems.

The fifth and final phase was to select the best computer system for the AAHT on the basis of the investigation conducted in phase four. Once the computer system was selected it was then possible to configure the computational system that would meet AAHT requirements.

<u>Use of FORTRAN</u>

Studies have shown that the number of lines of debugged code a programmer can produce per month on a project over a period of several years is approximately 100 to 200 lines, independent of the programming language used (Corbato, 1969). Only on small programs is higher productivity achieved. Therefore, if one FORTRAN statement

is equivalent to 5 to 10 assembly language statements, the productivity of a FORTRAN programmer would be 5 to 10 times that of an assembly language programmer.

Another argument against programming in assembly language is that assembly language coding, although vastly superior to pure machine language coding, is more time-consuming and difficult, and requires knowledge of the computer architecture. Effort by the programmer is required to learn the particular computer's assembly instructions. Since all problems must be broken into simple steps, much repetition and, with it, extra effort must be exerted by the programmer. Because of the resultant complexity of a particular programming task, there is a direct impact on the number of errors introduced and, thus, on the length of the debugging cycle. All of this is also true of maintaining assembly language code.

What is more, understanding someone else's assembly language program is very difficult. Furthermore, turnover of government software maintenance personnel is typically high. New programmers must spend a great amount of time learning the software before they can effectively maintain it. Often, their assignment ends shortly after or even before they can effectively maintain the software.

Many of the above-mentioned problems of assembly language programming are circumvented using a high-level language. The programming task is thereby simplified to the point where the programmer can perform his task nearly independently of the peculiarities of the computer being used. This is very desirable in the case of simulation modules, which are primarily composed of arithmetic and logic operations. Thus, FORTRAN, which was developed

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AH-64 FLIGHT AND WEAPONS SIMULATOR CONCEPT FORMULATION STUDY.(U)

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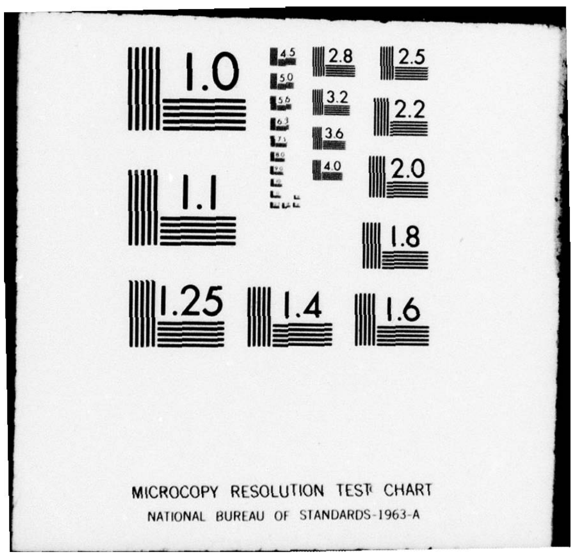
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

primarily for algebraic computations, is ideal for the aerodynamics and engines simulation modules. Since most FORTRAN's now include boolean logical operations, FORTRAN is also ideal for the remaining simulation modules.

However, real-time executive tasks such as I/O handlers and memory management, to name a few, are highly dependent upon the particular computer's architecture. Because assembly language is closely related to machine architecture, the programmer can take advantage of various hardware features that are unique to a particular computer. In addition, where the economics of the system dictate the use of a minimum amount of primary storage, the programmer is forced to economize in the number of instructions in his program. Assembly language allows the greatest such optimization of program size. Since large program size generally means longer execution times, program size becomes important to trainer performance in time-critical applications such as the real-time simulation executive; therefore, the executive should be written in assembly language.

Studies have shown that, in most programs, a small percentage of the total code is responsible for a large percentage of the execution time (Dardner and Heller, 1970). It is common to have 10 percent of the code using 90 percent of the execution time.

Assume, for example, that it requires 10 man-years to write some large program in FORTRAN and that the resulting program requires 100 sec to execute. Writing the whole program in assembly language would require about 50 to 100 man-years, due to the lower productivity of assembly language programmers; the final program, however, would execute in about 33 sec, since a clever programmer can outdo a clever compiler by a factor of 3 (Tannenbaum, 1976).

This is because the code generated by a compiler uses a subset, typically fewer than 20 percent, of the total number of available assembly language instructions (Tannenbaum, 1976). The instructions used are those of a general nature, and the subset can perform any required function. However, the remaining instructions are less general: they frequently combine two or more of the functions of the general instructions. The clever programmer, therefore, by using the more specific, multi-function instructions, can produce much more efficient code than a compiler does. Once again, this is very important to the real-time executive, which should therefore be written in assembly language.

Another approach (other than all assembly code or all high-level code) to producing software is called tuning. Tuning is based on the empirical observation (documented by Dardner and Heller, 1970) that, for most software programs, a small percentage of the total program is responsible for a disproportionate amount of execution time. All software is first written in a higher level language. Then, it is determined which parts account for most of the execution time. For example, assume that 10 percent of the total program accounts for 90 percent of the execution time. This means that for a 100-sec job, 90 sec are spent executing the critical 10 percent of code and 10 sec are spent executing the remaining 90 percent. The critical 10 percent is now improved by rewriting it in assembly language. Additional time is needed for tuning of the critical code, but its execution time is reduced, thus boosting its performance.

In the case of real-time aircraft simulation, we already know which portions of the code are responsible for disproportionate amounts of processing time. Typically, when all the programming is done in assembly language, the

real-time executive and trainer I/O, which comprise only 2 percent of the total code, require about 10 to 15 percent of the actual processing time (not including spare time). Therefore, if these portions of code (real-time executive and trainer I/O) are written in assembly language in advance, the expense of the tuning process is avoided but the performance advantages are retained.

The FORTRAN (FORmula TRANslation) language was designed for mathematic processes, as its name implies. Therefore, by reason of the language's design, FORTRAN has several characteristics which would limit the capabilities of some processing tasks. These characteristics are as follows:

1. Inflexibility of input format.
2. Lack of reentrancy.
3. Lack of efficient text handling capability.

Each of these characteristics and their impact on certain processing tasks is described below.

Because FORTRAN input formats are inflexible, the performance of the graphic page compiler and the off-line test programs would be degraded if FORTRAN teletype and card reader input handlers are coded in FORTRAN. These two programs must use either the teletype or card reader input handler to process each and every source statement that comprises the graphic page being compiled on the simulation module being tested. Most FORTRAN I/O is fixed-format; and, a greater possibility of I/O errors exists with fixed-format I/O than it does with free-format I/O. More important, unless the FORTRAN ERR function is implemented, an I/O error will cause program abortion. This is disastrous in terms of efficiency, since the programmer must recompile his graphic page or retest his module each

time a single error is encountered. Clearly, it is more desirable to discover all presently existing errors with a single execution of the graphic page compiler or the off-line test program.

The effectiveness of both the graphic page compiler and the off-line test program as development tools depends greatly upon the amount and specificity of error information that is provided to the programmer. With the ERR function, when an I/O statement error is detected, execution is not halted. Instead, execution is transferred to the instruction indicated in the ERR field of the I/O statement. An error message may then be printed and the error corrected or overlooked so that execution may continue with the next source statement of the graphic page being compiled or the module being tested. However, not all FORTRAN compilers implement the ERR function. Even with the ERR function, there is still the problem of supplying an adequate error message. When an input error occurs during the execution of a READ statement, for example, not only is it impossible to determine in which field of the data card the error exists; it may even be impossible, under some circumstances, to isolate the particular card being read when the error occurred. This severely limits the amount of helpful information that may be provided in the error message. Thus, a certain amount of expertise in successfully interpreting errors would be required by the applications programmer.

With assembly language, on the other hand, input format is much freer, data of any type may be entered in any order separated only by commas, and the chance of input errors is therefore minimized. Furthermore, if the card reader and teletype input handlers are written in assembly language, it is much easier to determine the nature of the error, and therefore, a much more specific

error message may be provided.

Fortran is not re-entrant. I/O handlers, however, are separate tasks which must be serially re-entrant unless a number of subroutines utilized by several handlers are incorporated as in-line code in each of the handlers. This results in very inefficient primary memory usage. Furthermore, because FORTRAN I/O handlers add a significant increase in overhead as compared to assembly language I/O handlers, the real-time performance of the simulator as a whole could be degraded if FORTRAN I/O handlers are used. I/O handlers - particularly disc I/O handlers - are highly executed, high priority items which are time-critical during real-time simulator operation. Thus, if I/O handlers, which are slow in assembly language, are written in FORTRAN, which is even slower, this could easily result in a slower response time for the module-related simulator cockpit instrumentation than for the aircraft instrumentation itself. Thus, the training value of the simulator is diminished.

FORTRAN's lack of efficient text handling capability would pose problems for the alphanumerics portions c the graphics programs. The alphanumeric displays would execute much faster if written in assembly language. Because non-byte-oriented FORTRAN is not designed for text processing, data must be either integer, real, complex or double precision; therefore, string and list processing routines written in FORTRAN would require extensive and complicated FORTRAN code, introducing much greater overhead, or would require storing one byte per word, resulting in poor memory utilization. It would be somewhat easier to process text with FORTRAN on a byte-addressable machine. However, to overcome the problems of how to move, split and concatenate character strings would still require

extensive or complicated FORTRAN code.

<u>Conclusions/Recommendations</u>. For real-time training simulators, real-time on-line processing involves two basic types of software: executive support software and the actual simulation software. The results of our training simulator survey show that the executive software (which includes I/O handlers and service modules) are very rarely, if ever, changed. Therefore, the development/acquisition cost of this software constitutes the bulk of its life-cycle cost.

The development/acquisition cost of the executive and its related processing tasks is directly related to the developer's prior experience with the chosen language. To date, not a single helicopter trainer real-time executive has been written in FORTRAN; all have been written in assembly language. Due to a number of previously mentioned, capability-limiting characteristics of FORTRAN, a great deal of thought, time and money needs to be invested to pioneer ways of accomplishing certain executive tasks. As a result, the development/acquisition cost of the executive software would surely be greater if coded in FORTRAN; and therefore, since development/acquisition costs are the greatest portion of the executive software life cycle costs, life cycle costs would also be increased with a FORTRAN real-time executive. However, for previously stated reasons, the use of assembly language would increase capabilities and improve performance of executive tasks without increasing life cycle costs. Therefore, it is recommended that the real-time executive and its related processing tasks be coded in assembly language.

Simulation software, on the other hand, is changed most often as a result of changes to the related aircraft system or improved aerodynamics data for the aircraft

being simulated; therefore, in the case of simulation software, maintenance costs constitute a much larger part of the life cycle costs. Since development and maintenance of FORTRAN simulation modules is easier, quicker and requires lower level personnel, and because coding the simulation modules in FORTRAN would not adversely affect simulation software performance, it is therefore recommended that the simulation software be coded in FORTRAN.

Finally, for the performance-related reasons previously stated, it is recommended that the graphic page compiler (preprocessor) and the off-line test program be written in assembly language.

Use of Vendor's Operating System As Real-Time Executive

Several factors must be considered before recommending the vendor-supplied operating system be used as the real-time simulation executive. They are: cost, memory utilization, and feasibility and performance. Each of these factors are addressed separately in subsequent paragraphs.

Cost. The results of our informal user's survey indicate that the real-time executive is rarely, if ever, modified after product delivery. Therefore, the great bulk of the life-cycle support costs is the development cost, in the case of a contractor-developed real-time executive, or the acquisition cost, in the case of a vendor-supplied Operating System (OS). How great an acquisition/development cost saving, if any, is realized through use of the vendor-supplied OS as the real-time executive depends largely upon the contractor's experience with the chosen computer system.

The development cost of a real-time executive can

also be nil or negligible if the contractor has already developed a proven real-time executive for a previous simulator on the same computer system that is chosen for the AAHT. For example, the real-time executive developed for the A-4M trainer has not been changed to date. The real-time executive for the A4-International used the A-4M executive as a baseline and expanded its capabilities. The A-4KU uses the exact same real-time executive that was developed for the A4 International. The B-52 G and H Operational Flight Trainers (OFT's) also used the A4 International executive as a baseline and incorporated multi-task programming and other enhancements. Any further B-52 OFT's will use the same real-time executive, with the only foreseeable enhancement being the possible modification of existing I/O handlers to accommodate different peripherals. This type of executive reutilization is possible only because the same computer system was used on all of the trainers mentioned. However, if the contractor has had no previous experience with the proposed computer system, five to six man-years of effort may be required to develop a real-time executive.

The vendor-supplied operating system is purchased whether or not it is used as a real-time executive; it is needed for off-line development of simulation modules. In theory then, the development/acquisition cost is zero when the vendor-supplied operating system is used as the real-time executive. In practice, however, the vendor-supplied operating system requires simulation-tailored extensions to reduce the resulting increase in overhead which can, if the increase is large, degrade total simulator performance. The development costs for these extensions would again depend on the contractor's familiarity with the computer system, and thus, its operating

system software. If the contractor is familiar with the operating system, extending it may be little or no more costly than enhancing the contractor's own real-time executive. On the other hand, if the contractor is totally unfamiliar with the proposed computer system, development of vendor-supplied operating system extensions would be much less costly than developing a real-time executive.

Memory Utilization. The manufacturer's operating system requires more memory than does a contractor-developed real-time executive. This is because the manufacturer produces a general purpose operating system that will satisfy the requirements of all its users. As a result, there are features which are unnecessary for flight trainer applications, but which nevertheless introduce increased overhead and require greater storage space. These effects are increased with multicomputer configurations. Instead of duplicating the manufacturer's operating system in each of the computers of a multicomputer configuration, a more efficient system would be to make one CPU, with the vendor-supplied operating system, the MASTER CPU, with contractor developed special purpose executives resident in each of the remaining (SLAVE) computers. This would decrease the total system storage required for operating system/executive software, while at the same time eliminating the SLAVE processor overhead that would be introduced if the SLAVE computers used the vendor-supplied OS.

Feasibility and Performance. In order to adequately support a flight trainer, an operating system must have the following specific capabilities:

- Event-driven multitasking
- Capability of supporting multiple foreground tasks and a batch-oriented background task concurrently
- At least 30 software priority levels
- Interrupt and trap handlers
- On-line resolution of external references for foreground tasks
- Dynamic memory allocation of foreground and background tasks
- Software and operator task activation
- Queued I/O
- Re-entrant task intercommunication and coordination routines, available to foreground tasks
- Global common memory
- Position-independent symbolic global common references
- File management and assignment
- Three levels of system generation:
    1. Rebuild disc (complete system generation)
    2. Alteration of resident OS portions while keeping permanent files intact
    3. Load a fresh copy of OS from disc
- Servicing of all standard peripheral devices

Cost Effectiveness of On-Line versus Off-Line Diagnostics

Those types of memory diagnostics (for either primary or on-line secondary storage) that continually write various data patterns to, and read them from, memory,

obliterating its former contents and thereby precluding real-time simulator operation, must always be run off-line. However, certain types of limited diagnostics may be run on primary memory. Address decode lines and data paths may be checked by isolating periods of time in which a single word in each 8K memory module is written and read back. This single word in each 8K module must be test-dedicated: it must not contain data to be used for any other purpose. A second type of limited memory diagnostic would be to perform a limited memory integrity check by simply reading each word from memory and checking its parity. However, this sort of software parity check is useful and cost effective only if parity checking is not offered by the computer vendor.

On-line diagnostics for the mainframe or mainframe option boards are of limited value since a mainframe fault will in all likelihood preclude simulator operation.

The most practical and effective use of on-line fault diagnosis is made in the case of off-line peripherals such as a card reader, line printer or magnetic tape unit. Computer maintenance personnel typically "shut down" the software currently being executed in order to run their off-line diagnostics. In the case of a flight trainer, this means the trainer must sit idle while diagnostics are being run. If the fault occurred in one of the peripherals used only for off-line development, such as a card reader or line printer, on-line diagnostics would allow simulator support and diagnostic execution concurrently, as long as the computer was not overloaded. (With a 100% spare processing time requirement, a computer overload due to on-line diagnostic execution is virtually impossible).

Often, once the problem is believed to be remedied, computer maintenance personnel may let a diagnostic run for

hours at a time to assure that the fault is "permanently" fixed, and is not a short-term periodically recurring one. These hours could also be used for concurrent simulator support and diagnostic execution if on-line diagnostics are used.

Even if on-line diagnostics exist, however, the extent of their use and therefore, their cost effectiveness, depends very much on the particular maintenance policy in effect. If an organic computer maintenance capability is planned, then use of on-line diagnostics to save trainer down-time may be enforced. Or, if the computer site is a time and materials customer, the vendor's field engineer may be persuaded to bear with on-line diagnostics so that the trainer may be supported concurrently. However, if contract service is obtained from the computer vendor, then the vendor's field service personnel may very likely "shut down" the software currently being executed and run their *off-line* diagnostics in order to get off the customer site as soon as possible.

Regardless of the possible benefits to be achieved by the use of on-line diagnostics, Sperry SECOR recommends that they be required only if they are available from the computer vendor. The contractor could provide on-line diagnostics only at a very great expense. The computer vendor, on the other hand, already has a thorough knowledge of the hardware involved. The vendor's effort to produce on-line diagnostics is limited to adapting their own off-line diagnostics for on-line use. And, they have a much wider market over which to distribute the cost of such development. For these three reasons, the vendor can produce much less expensive on-line diagnostics than could the contractor. For example, SEL provides on-line diagnostics for its mainframe, floating-point firmware and mag tape transport for the combined price of $125 for binary cards or $175 for source mag tape. They charge only $10 for a

technical description manual which describes all three on-line diagnostics. No contractor could begin to meet these prices.

Therefore, Sperry SECOR recommends that any available on-line diagnostics be purchased from the computer vendor and used as extensively as possible with the purpose of determining which, if any, benefits accrue therefrom.

Use of MOS Memory vs Core Memory

None of the candidate computers provide metal-oxide-semiconductor (MOS) memory. However, since MOS memory is being offered in a greater and greater number of computer systems, it may be beneficial to future trainers to discuss the various advantages and disadvantages of core and MOS memories.

Reliability. The greater reliability of core memory, along with other factors such as proven design and availability of core, are the reason why core memories are still preferred, and why MOS memories were not used sooner in mini-computers of the 24- and 32-bit variety. Unfortunately, because of the multiplicity of MOS RAM cell designs and the frequency with which new cell designs evolve, it is impractical to quote a numerical mean-time-between-failure (MTBF) value for the reliability of a specific MOS technology, (n-MOS, p-MOS or C/MOS). Because of the great variety of cell designs, there are exceptions to almost every characteristic of a specific MOS technology. Therefore, one must be very careful to limit comparisons to specific memory cells, and to quote MTBF values of specific memories.

A principal factor that definitely affects MOS reliability is junction temperature, which is directly related to power dissipation. The lower the power dissipation, the lower the junction temperature and, as a result, the greater the reliability that may be achieved.

There is also an economic deterrent in the establishment of MOS reliabilities. In the case of bipolar semiconductor products, millions of test hours of reliability data were sponsored by the military. Since MOS circuits have to date been used primarily in consumer and industrial applications, large sums of military money have not been made available for generation of MOS reliability data.

Despite the impediments imposed by economics and diversity of design, MOS reliabilities have improved steadily. In 1972 MOS circuitry had reached the same reliability levels achieved by bipolar circuitry only five years previously. At present, Varian Data Machines gives an MTBF of 38,600 hours (over four years) for its V76 32K 660ns MOS memory. (The V76 is not available with core memory). Varian's stated MTBF for their V75 16K MOS memories is 55,000 hours; for 16K core memories, 73,000 hours. Here again, core is more reliable. However, a memory with a MTBF of 55,000 may hardly be considered unreliable. In addition, core memory for the V75 is available in 990ns and 660ns versions; but V75 MOS memory has a 330ns cycle time. Therefore, it may be considered worthwhile to suffer a 25% decrease in reliability to gain a 100% increase in performance, especially in time-critical applications.

Soon, with continuing increases in MOS reliability, one can expect to gain increases in performance without suffering any loss of reliability when choosing MOS memory.

<u>Speed</u>. Speed is one of the two greatest advantages that MOS memories have over core memories. However, there is a speed vs power trade-off that has resulted in little or no improvement over core access and cycle times by most of the MOS memories now available in commercial computer systems. Some commercially available n-MOS memories offer access times of less than 100ns; but, because these memories require multiple power supplies or dissipate high power,

they are not being widely used in commercial computer systems. These MOS memories that are being widely used dissipate less power, roughly less than 200 milliwatts, but have access times well above 500 ns. Our previous example, the VARIAN V76 memory, for instance, has a 660ns cycle time. This is not a particularly impressive speed when one considers that Systems Electronics Laboratories offer 600ns core memories. On the other hand, the Varian V75 may be bought with 330ns MOS memory, which by Varian's figures is at present even more reliable than its V76 660ns MOS memory.

Constant improvements in the speed-to-power dissipation ratio of MOS memories, and in particular n-MOS memories, will surely cause more changeovers from core to MOS in the next five years. Mostek Corporation has recently released a 4K static n-MOS RAM which achieves a maximum access time of 220ns (150ns typical) and a maximum cycle time of only 260ns while dissipating only 80 milliwatts of active power at 4 Mhertz and a very low 8 milliwatts in precharge or standby mode. As additional low-power mode of 1.0 milliwatt is available for battery back-up operation, achieved simply by lowering the power supply voltage from 56 to 2 or 3 volts. This and future MOS technological developments will surely hasten the wider acceptance of MOS memory by computer system manufacturers.

<u>Volatility</u>. In many harsh environments core is still preferred because of its nonvolatility. MOS memory, of course, is volatile. However, users can operate with battery back-up for their MOS memory systems, allowing them to retain data even under conditions of sudden power loss. Most manufacturers offer battery back-up as an option for MOS memory, with a corresponding increase in price. Varian charges $500 for its Data Save power supply and battery back-up for MOS memory. This added expense must be considered when discussing the total cost of MOS memory. Thus, in terms of volatility, MOS memory with battery back-up is

a viable alternative to core memory in all but the most harsh environments.

Cost. Cost is the second of two advantages that MOS memory has over core, especially if one considers the price/performance ratio. Table 8 presents the cost per bit of the various VARIAN memories. As Table 8 shows, the best price per bit is achieved with 660 ns MOS. The best price/performance ratio is also achieved with 660 ns MOS; the worst price/performance ratio is achieved with 660ns core.

At present, most manufacturers offer MOS memory at lower cycle times (better performance), but at higher prices than core memory. This is because core memory is widely used and is therefore produced in great quantities. In addition, the technology used in core manufacture is well in hand; whereas, MOS technologies are still evolving. The greatest cost in manufacturing core memory is the cost of threading the magnetic donuts themselves. This is painstaking, time-consuming work performed by hand - and is therefore an expensive process. Because MOS memories lend themselves more readily to mass production, as MOS memory use increases and MOS technology completes its evolution, the cost of MOS memories should decrease drastically. In the meantime, MOS memories still provide the best price/performance ratio.

Conclusions. (1) Due to the decreasing price and increasing reliability of MOS memory, it should be seriously considered if not specified for future Army trainer computer systems. (2) If MOS memory is to be considered for future trainers, battery back-up should be an absolute requirement.

Computer Evaluation Criteria

Computer system criteria are divided into two types, pass/fail criteria and quantitative/qualitative criteria. There are six criteria which the AAHT computer system must meet in order to support the AAHT. Pass/fail criteria include:

Table 8. Price and Performance of Varian Memories:

MOS vs. Core

Computer	Cycle Time (Performance)	Technology	Price (cents/bit)	Price/ ** Performance
V75	990ns	core	1.3/1.4*	3.94/4.24*
	660ns	core	2.7	5.4
	330ns	n-MOS	3.7/3.8*	3.7/3.8*
V76	660ns	n-MOS	1.1	2.2
V77	660ns	n-MOS	1.1	2.2

* Depending upon whether parity bits (1 per byte) are included. Lower value without parity/higher valve with parity.

** Figures are based on a performance evaluation as follows:

330 ns = 1
660 ns = 1/2
990 ns = 1/3

In this way the higher the price, the higher the price/performance ratio; and, the higher the performance, the lower the price/performance ratio. This results in the best price/performance ratio being the lowest value. The price/performance ratio figures are in units of price/bit-performance.

a. Program protection
b. Floating point
c. Interrupt and trap handling
d. Multiprocessor support
e. CPU controllability of I/O
f. Extendability of instruction set

The first five criteria are self-explanatory. The extendability of the instruction set is important in terms of upward compatibility. If little or no extendability exists (few, if any, unused instruction codes), then to add new instructions - thereby providing new capabilities - may require revision of the instruction format. When the instruction format is revised, the existing software is rendered useless on the "revised" machine. The greater the percentage of possible instruction codes that are unused, the longer the existing software may be used on newer models of the same computer, adding tremendously to the software's upward compatibility and to the length of the software life cycle.

Quantitative/qualitative criteria were established in the following areas:

a. Throughput requirement
b. Primary storage requirement
c. Secondary storage requirement
d. Peripheral requirements
e. Instruction repertoire
f. Software requirements

These areas are discussed separately below.

Throughput and Primary Storage Requirements. Sperry's approach to establishing the computer system throughput and primary storage criteria for the AAHT was to perform each of the steps detailed in the following paragraphs.

The first step was to identify the top-level, functional computer program components (i.e., aerodynamics, on-board systems, instructional features). A further break down to major computer program modules was required to achieve a high confidence factor in the areas of instruction and data counts. A list of the major computer program modules is provided in Table 9.

The second step was to determine the requirements pertaining to each computer program module, such as:

1. Extent of simulation
2. Method of implementation
3. Instructional features
4. Data availability
5. Iteration rates.

The highest iteration rate of 30 Hertz is the rate at which data must be provided to the visual system, therefore, this rate should be the minimum specified for the AAHT with a CGI visual system. The lower rates were selected based on several factors. The 15 and 7.5-Hz rates are multiples of the 3-Hz rate, thus providing a constant relationship between parameter computations and ease of executive control. The 2-Hz and 1-Hz rates were selected for implementation of the instructional features of the F-16 TFS. The 2-Hz update rate will be utilized for the alphanumeric displays and performance monitoring. The 2-Hz rate is used to optimize displayed data accurately while ensuring that the display is readable. The 1-Hz rate is used for instructional features such as real-time initial conditions recording. These instructional features will occur within 40 milliseconds of the instructor action; however, they will only occur once per second. The rate selections of the remaining systems were established to provide the proper response required for simulation. Sperry has successfully simulated many gas turbine aircraft engines using a 10-Hz rate, which is less than the selected rate (15 Hz). With this iteration rate,

TABLE 9. COMPUTER PROGRAM MODULE LIST

Real-Time Routines

Real-Time Operating System	Electrical System and Auxiliary Power Unit
Input/Output Handlers	Hydraulic System
Math/Function Subroutines	Terrain Mapping
I.S. Controller	Communications/Navigation
I.S. Display Data	Environment (Oxygen System)
I.S. Printouts	Weapons Scoring
Auto Playback/Demo	Crash
I.S. R/T Initial Condition Record	Freeze/Parameter Freeze
I.S. Reset	Visual
Cycle Time Verification	Voice Recorder
DRU Program	Flight Instruments
Instrument Scaling	Caution and Warning Panel
Fire Control, Doppler Navigation	Icing, Pitot Static
Aerodynamics	Fire Detection (Panel)
Engines	Wheel Brakes
Motion System	SAS
FLT Controls, BUCS	Flaps
Fuel System	Ejection
	Engine Instruments, Engine Oil

Background Routines

Library Data File Handlers	Real-Time Interface Equipment Diagnostic
Preflight Check/Calibration	Simulation Verification Program
Radio Nav Station Support	Computer Program System Support Programs
AN/Graphic CRT Display Gen.	
Tactics Mission File Support	

transient engine response in starting, shutdown, acceleration and deceleration has been exactly reproduced. The recommended iteration rates for each module are shown in the second column of Table 10.

Step two provides the information necessary for step three, sizing each computer program module. Sizing for each computer module was accomplished by performing the following three tasks:

1. Determine the total number of instructions
2. Determine the total data and constant storage
3. Determine the number of instructions executed per frame

The results of these determinations are shown in the third through fifth columns of Table 10. Tasks one and two are self-explanatory. Task three is not directly related to sizing; however, it is a very important factor in determining the computer time loading (the total number of instructions that must be executed in a given time period). Real-time aircraft simulation programs are written using various types of programming techniques, such as branching and repetitive loops. The number of instructions that are executed in each frame is determined by which programming techniques are implemented; and, it is the total number of instructions executed in each frame - not module size - that determines the computer time loading. Therefore, any calculation of time-loading requirements that is not based upon the number of instructions executed per frame is invalid.

The fourth step was to calculate the total number of instructions that must be executed each second. This was accomplished by multiplying the number of instructions executed per frame by the require iteration rate (in seconds) and summing the results. This result provided the basic computer instruction throughput required for simulation program implementation.

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SIMULATION SYSTEMS

TABLE 10 . COMPUTER PERFORMANCE REQUIREMENTS ANALYSIS

PROGRAM NAME	ITERATIONS PER SEC	MEMORY		EXECUTED INSTRUCTIONS	mSEC/ FRAME	mSEC/ CYCLE	INSTRUCTIONS/ SECOND	%FORTRAN CODE
		INSTRUCTIONS	DATA					
RT Exec/OS	30	12,000	2,000	1,000			30,000	0
I/O Handlers	30	1,000	200	300			9,000	0
I.S. Cntrllr	2	1,200	6,500	600			1,200	0
I.S. Printouts	2	400	200	300			600	60
I.S. Init.Cond.	1	150	50	150			150	0
I.S. Reset	1	120	80	120			120	0
Freeze/Para Frz	30	100	20	50			1,500	90
Playback/Demo	30	450	3,000	500			15,000	0
Voice Recorder	30	250	50	150			4,500	60
Instrmt Scaling	30	100	300	180			5,400	0
C.T. Verifictn	30	70	200	50			1,500	0
DRU	30	2,500	500	150			4,500	0
Eng Inst/Eng Oil	30	100	100	200			6,000	100
Caution/Warning	30	150	75	225			6,750	100
Motion	30	400	50	380			11,400	100
Crash	30	100	20	80			2,400	100
Icing/Pitot Stat	7.5	100	50	75			562.5	100
Fire Detect	7.5	50	25	40			300	100
SAS	30	200	10	190			5,700	100
Engines	15	900	1,000	1,300			19,500	100
Fuel	15	400	50	380			5,700	100
Hydraulic	15	300	50	200			3,000	100
Elect Sys/APU	7.5	150	10	150			1,125	100
Oxygen	7.5	100	50	50			375	100
Flaps	15	70	5	70			1,050	100

TABLE 10. COMPUTER PERFORMANCE REQUIREMENTS ANALYSIS (Con't)

PROGRAM NAME	ITERATIONS PER SEC	MEMORY		EXECUTED INSTRUCTIONS	mSEC/ FRAME	mSEC/ CYCLE	INSTRUCTIONS/ SECOND	%FORTRAN CODE
		INSTRUCTIONS	DATA					
Ejection	7.5	60	20	50			375	100
Aerodynamics	30	1,500	550	1,500			45,000	100
Flt Cntrls/BUCS	30	600	200	420			12,600	100
Visual	30	500	50	500			15,000	100
Fire Cntrl/Dop Nav	30	500	100	500			15,000	100
Terrain Mapping	30	200	150	100			3,000	100
Comm/Nav	15	500	50	350			5,250	100
Weapons Scoring	30	500	100	500			15,000	100
Wheel Brakes	7.5	30	-----	30			225	100
Math Func Subs	30	500	50	1,000			30,000	0
	15	------	-----	800			12,000	0
	7.5	------	-----	400			3,000	0
Flt Instruments	30	500	10	400			12,000	100
Data Pool			5,000					
SUBTOTALS		26,750	20,875				305,782.5	
REQUIRED SPARE		26,750	20,875				305,782.5	
TOTALS		53,500	41,750				611,565	

Steps one through four result in the establishment of the computer system throughput and primary storage requrements. Table 10 shows that the total number of instructions that must be executed each second to support the AAHT is 305,782.5. With 100% spare processing time the required system throughput is 611,565 instructions per second. The total primary storage required is equal to the total number of instructions (26,750) plus the total number of data words and constants (20,875), or 47,625. With a 100% spare memory requirement, the total primary storage required for the AAHT is 95,250 words or 381,000 bytes.

Secondary Storage Requirements. Timing considerations require that record/playback data reside on a dedicated disc. Therefore, at least two discs are required, one for program and data storage (mission data disc) and a second for playback and automatic demonstration storage (playback/demo data disc). Table 11 lists the storage allocation for both discs. With 100% spare storage, a minimum capacity of 52 Mbytes is required for the playback/demo data disc.

Files should be structured so that disc accessing requires a minimum amount of head movement. Considering the continuous writing/reading required by record/playback, CRT and record/playback data files should be contiguous, providing minimum head travel on the respective disc drives.

Peripheral Requirements. In order to facilitate software configuration management, Sperry SECOR recommends two separate system configurations: a support center computational system configuration to be installed at the first site, Fort Rucker, and a general computational system configuration without permanent software modification capabilities to be installed at all other sites. The support center configuration shall be identical to the general configuration except for the addition of those peripheral and software

TABLE 11. MASS STORAGE ALLOCATION

Mission Data Disc		Playback/Demo Data Disc	
Operating System and Program Storage	5 Mbytes	Operating System and Program Storage	5 Mbytes
Data File Storage	5 Mbytes	Playback (5 min)	1 Mbyte
Terrain Mapping	9 Mbytes	Demo (10 min X 10 demos)	20 Mbytes
TOTAL	19 Mbytes	TOTAL	26 Mbytes

units necessary for software development and permanent modification. All permanent changes to software should be made at the support center site. The general configuration sites will provide the capability to change data base items and mission support data (such as radio facilities data) only.

Support Center Peripherals. One card reader and one line printer are required for software development and maintenance. In addition, a magnetic tape transport is required for off-line back-up and program library storage.

General Configuration Peripherals (All Sites). An interactive device is required for machine operator interface. Sperry SECOR recommends a CRT/keyboard/cassette/hard copy unit. A display terminal offers two main advantages over teleprinter terminals: extensive editing and block transfer of the edited message to the computer. The cassette capability allows on-site changes to the data base items and mission support data. It also allows new or updated software, generated or modified at the support center site, to be entered into the general configuration site computer.

Instruction Repertoire Requirements. Whether FORTRAN or assembly language is used, text handling is much easier and efficient with byte manipulation instructions. Also, because many simulation modules are Boolean systems (lights, switches, etc.) byte-sized flag representations are necessary. In addition, since simulation modules utilize many single-bit DI's, bit manipulation instructions are also required for easy and efficient coding of simulation software. Therefore, any candidate computer should have an adequate range of both byte and bit manipulation instructions, which include logical operations, in addition to the usual complement of instructions.

Software Requirements. The required computer program system software components are shown in Figure 39. Because the Operating System and the FORTRAN compiler have a direct effect on the real-time performance of the simulation programs, a list of capabilities required for support of real-time flight simulators was prepared for use in evaluating the candidate vendor's offerings in these two areas. Required Operating System capabilities are listed under the discussion of the use of the vendor's operating system as the real-time executive. Required FORTRAN compiler capabilities are as follows, ranked in order of descending importance:

1. Should make efficient use of machine architecture.
2. Compiler output should be object code.
3. In-line coding of Intrinsic Functions.
4. Should pass variable between registers if a single variable is passed in a subroutine or function call.
5. Should include byte and bit manipulation capabilities.
6. Should handle in-line assembly language code.
7. Should be a diagnostic compiler similar to WATFOR/WATFIV on the IBM 360, to DITRAN on the UNIVAC 1108, or to FORGO on the Harris Slash 5. That is, it should provide execution time-checking to detect more subtle run-time errors. Such checks should include detection of (a) undefined variables, and (b) subscripts that exceed array bounds as defined in their dimension statements.
8. Should provide the precise location of compile-time errors within the source program.
9. Should allow expressions to contain mixed-mode elements.
10. Encode and Decode facilities (to provide storage-to-storage data manipulations).
11. Multiple entry to functions or subroutines.
12. ERR Function.

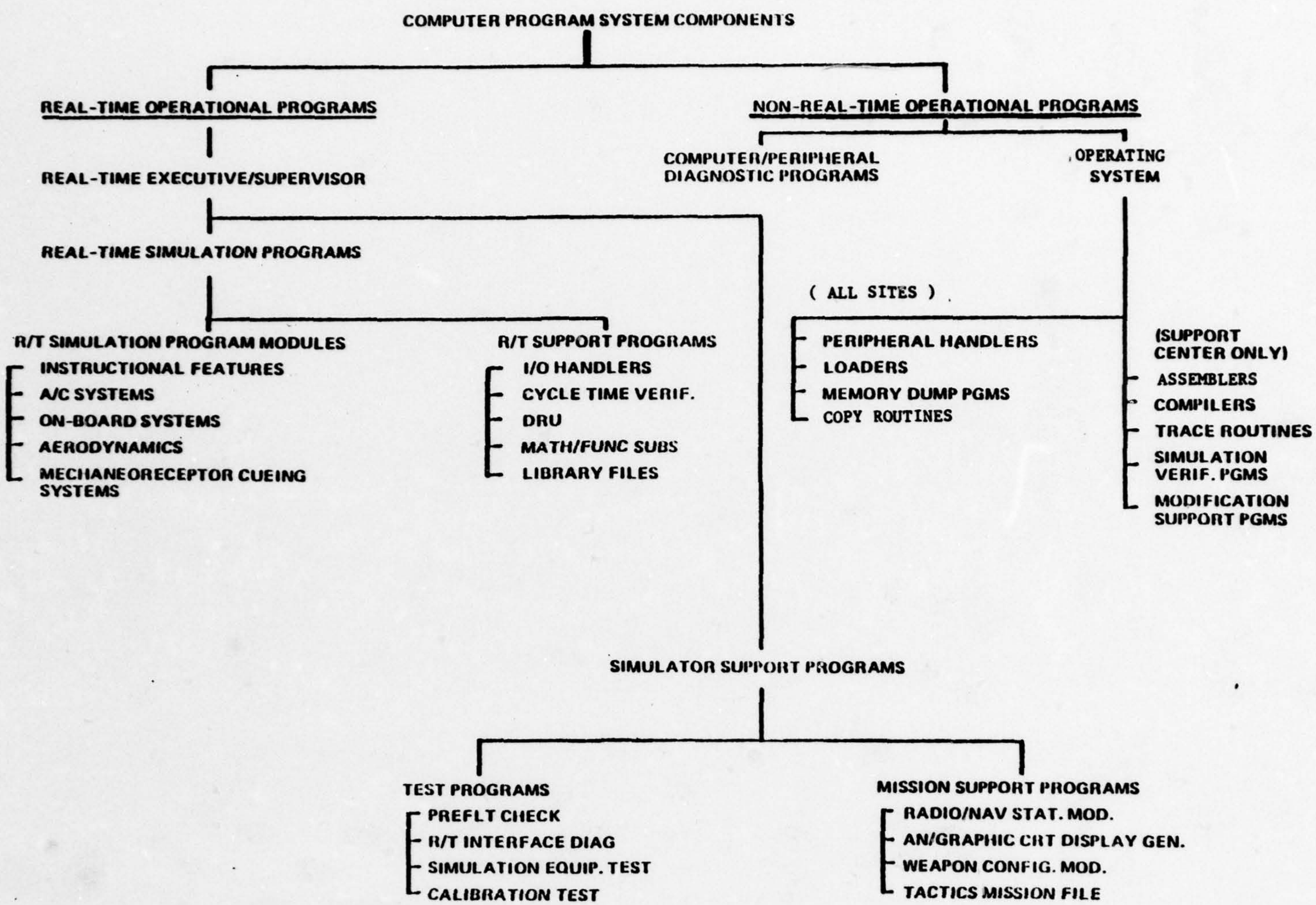

FIGURE 39. COMPUTER PROGRAM SYSTEM COMPONENTS

Priorities were established on the basis of compiler use for simulation modules only. Highest priority was given to those features that generate the most efficient code. Next highest priority was given to those features that provide the best debug aids. Lowest priority was given to those features which are merely convenient for the applications programmer.

Survey of Available 32-Bit Minicomputers

Available Models. There are only two domestic manufacturers that provide true 32-bit minicomputers: Systems Engineering Laboratories (SEL) and Interdata. A number of minis, such as the Data General S/230 Eclipse or the PDP 11/70 have 32-bit instruction formats; some, such as the Interdata 7/32, may even be purchased with 32-bit CPU register bus organization. However, all of these minis, with few exceptions, have 16-bit memory bus widths. Therefore, to perform a 32-bit operation they must do two loads and two stores. If the CPU register bus organization is only 16 bits, they must also use two CPU registers. All of this drags down their effective throughput. Only the Interdata 8/32 and the SEL 32/35, 32/55 and 32/75 have both 32-bit CPU register organization and a 32-bit memory bus width. Of these, the Interdata 8/32, SEL 32/35 and SEL 32/55 are available presently. The SEL 32/75 will be available in October 1977. All four of these computers meet all of the pass/fail criteria established previously. Results of the evaluation of these computer systems against the established qualitative/quantitative criteria are discussed below.

Throughput. The calculation of average instruction execution rates for candidate computers are illustrated in Tables 12 through 15. The significant difference between the SEL 32/75 and previous SEL 32 models is due to the change from firmware-implemented to hardware-implemented

TABLE 12. SEL 32/35

AVERAGE INSTRUCTION EXECUTION RATE

Instruction Class	Fractional Usage	usec/Instruction	Product
Load, Store	.30	1.8	.540
Add, Subtract*	.08	1.35	.108
Add, Subtract (Fl. Pt.)	.04	2.7	.108
Branch, Transfer**	.20	1.35	.270
Compare*	.05	1.35	.068
Multiply	.05	5.7	.285
Multiply (Fl. Pt.)	.04	7.3	.292
Divide	.01	9.0	.090
Divide (Fl. Pt.)	.01	9.3	.093
Boolean*	.20	1.35	.270
Shift (5 places)	.02	2.2	.044
	1.00		2.168

Average Instruction Execution Rate 461,255 Instructions/sec

* Register-to-Register operations require 0.9 μsec, Memory Reference requires 1.8 μsec (average 1.35 μsec).

** Branch requires 0.9 μsec if fall through or 1.8 μsec if branch taken (1.35 μsec average).

Fl. Pt.: Single Precision Firmware Floating Point Arithmetic

TABLE 13. SEL 32/55

AVERAGE INSTRUCTION EXECUTION RATE

Instruction Class	Fractional Usage	usec/Instruction	Product
Load, Store	.30	1.2	.360
Add, Subtract*	.08	0.9	.072
Add, Subtract (Fl. Pt.)	.04	3.0	.120
Branch, Transfer*	.20	0.9	.180
Compare*	.05	0.9	.045
Multiply	.05	5.7	.285
Multiply (Fl. Pt.)	.04	6.1	.244
Divide	.01	9.0	.090
Divide (Fl. Pt.)	.01	9.1	.091
Boolean*	.20	0.9	.180
Shift (5 places)	.02	2.2	.044
	1.00		1.711 usec

Average Instruction Execution Rate 584,454 Instructions/sec

* Register-to-Register operations require 0.6 µsec, Memory Reference required 1.2 µsec (average 0.9 µsec)

** Branch Requires 0.6 µsec if fall through or 1.2 µsec if branch taken (0.9 µsec average)

Fl. Pt.: Single Precision Firmware Floating Point Arithmetic

TABLE 14. SEL 32/75

AVERAGE INSTRUCTION EXECUTION RATE

Instruction Class	Fractional Usage	usec/Instruction	Product
Load, Store	.30	1.2	.360
Add, Subtract*	.08	0.9	.072
Add, Subtract (Fl. Pt.)	.04	1.95	.078
Branch, Transfer**	.20	0.9	.180
Compare*	.05	0.9	.045
Multiply	.05	5.7	.285
Multiply (Fl. Pt.)	.04	3.95	.158
Divide	.01	9.0	.090
Divide (Fl. Pt.)	.01	4.1	.041
Boolean*	.20	0.9	.180
Shift (5 places)	.02	2.2	.044
	1.00		1.533

Average Instruction Execution Rate 652,316 Instructions/sec

* Register-to-Register operations require 0.6 μsec, Memory Reference requires 1.2 μsec (average 0.9 μsec)

** Branch Requires 0.6 μsec if fall through or 1.2 μsec if branch taken (0.9 μsec average)

Fl. Pt.: Single Precision Hardware Floating Point Arithmetic

TABLE 15. INTERDATA 8/32

AVERAGE INSTRUCTION EXECUTION RATE

Instruction Class	Fractional Usage	µsec/Instruction	Product
Load, Store**	.30	1.6	.480
Add, Subtract	.08	0.8	.064
Add, Subtract (Fl. Pt.)	.04	1.8	.072
Branch, Transfer*	.20	1.8	.360
Compare	.05	0.8	.040
Multiply	.05	3.1	.155
Multiply (Fl. Pt.)	.04	2.1	.084
Divide	.01	5.7	.057
Divide (Fl. Pt.)	.01	3.9	.039
Boolean	.20	0.8	.160
Shift (5 places)	.02	2.9	.058
	1.00		1.569

Average Instruction Execution Rate 637,349 Instructions/sec

* Register-to-Register operations require 0.4 µsec, memory reference operations require 1.25 µsec (average 0.83 µsec)

** Load from memory operations require 1.25 µsec, store operations require 2.00 µsec (average 1.6 µsec)

Fl. Pt.: Single Precision Hardware Floating Point Arithmetic

floating point arithmetic. Only the SEL 32/75 and the Interdata 8/32 can meet the 100% spare processing time requirements without additional CPU's.

Primary Storage. All four of the candidate computers may be configured with 1 Mbyte of primary storage, which far exceeds the 0.381 Mbyte requirement for the AAHT. The SEL 32/75 may be configured with as much as 8 Mbytes of primary storage.

Secondary Storage. Both manufacturers supply both 40 and 80-Mbyte moving head discs. Without considering the spare storage requirement, a 40-Mbyte capacity is sufficient for both the mission data and playback/demo data discs. If 40-Mbyte discs were chosen, four moving head disc drives would be required to meet the 100% spare storage requirement. This is by no means an economical approach. Therefore, two 80-Mbyte discs are recommended.

To insure that a disc failure does not obviate trainer operation, Sperry SECOR recommends that a backup unit be provided. There are two possible approaches to providing secondary storage backup: on-line or off-line. With on-line backup, the backup units are part of the system configuration: data is simultaneously written to both the primary disc and its backup, while being read only from the primary disc. On-line backup requires a slight increase in programming costs, decreases the system MTBF and doubles the secondary storage materials cost of each trainer. The advantages to be gained with on-line backup are (1) only a momentary interruption in the current training exercise, and (2) no loss of data recorded for playback. With off-line backup, the backup unit is physically disconnected from the computer system and sits idle until an error is detected in any of the primary units. Off-line backup offers many advantages:

1. The training exericse is interrupted only long enough to exchange disc units.

2. Secondary storage materials cost are increased only by 50% for the first trainer at any particular site. There is no increase in secondary storage materials cost for any subsequent trainer at the same site since one disc unit may serve as off-line back-up for up to four trainers.
3. Off-line backup has no inflating effect on programming costs.
4. With off-line backup the spare disc does not effect the system MTBF.

There is one minor disadvantage with off-line backup. All of the recorded data currently residing on the faulty record/playback disc unit will be lost. That is, the playback capability will not be available for the first n minutes of trainer operation after a disc exchange has been made, where n represents the provided maximum playback duration.

Therefore, because off-line backup provides the most economical approach to secondary storage backup, while imposing only a limited curtailment of capabilities, Sperry SECOR recommends that a single off-line 80-Mbyte moving head disc be provided with only the <u>first</u> trainer at each site.

A comparison of the 80-Mbyte moving head disc drives that are provided by the candidate computer manufacturers is provided in Table 16. Note that the operational features of both disc drives are identical. However, the SEL-provided disc drive is the optimum drive since it provides a larger actual storage capacity at a much lower price when purchased directly from Control Data Corporation. The MSM80 is available only from Interdata.

<u>Peripherals</u>. Both the SEL 32/75 and Interdata 8/32 may be configured with the peripherals required for the support center. Interdata supplies a CRT, keyboard and hard copy device and inter-tape cassette unit to meet the operator terminal requirement.

Table 16. 80MB Disc Drive Comparison

	SEL	Interdata
Model Number	9320	MSM80
Actual Storage Capacity (bytes)	72,687,360	67,200,000
Transfer Rate	1.2 Mbyte	1.2 Mbyte
Rotational Speed	3600 RPM	3600 RPM
Access Time:		
Minimum	7 ms	7 ms
Average	30 ms	30 ms
Maximum	55 ms	55 ms
Cost:		
Disc & Controller	12,700*	25,000**

* Controller purchased from SEL at $5,000, 80 Mbyte Disc Drive Model 9762 purchased from CDC at $7,700.

** Disc and Controller must be purchased together.

SEL does not provide the required terminal equipment; however, the SEL can be interfaced to a Haziltine H2000 CRT/keyboard with thermal printer and dual tape cassette unit.

Instruction Repertoire. Both SEL and Interdata provide four bit manipulation instructions which, although not exactly the same, are functionally equivalent. Both SEL and Interdata provide byte manipulation instruction that facilitate text handling. However, SEL's instruction repertoire was judged to be superior since only SEL's instruction set includes instructions to perform logical operations (AND, OR, exclusive OR) on byte values. This is important in handling boolean flags. Since Interdata's instruction set does not allow a byte value from memory to be logically combined with a register's contents, flags must be stored as halfword values. With the great number of boolean flags that are used in real-time aircraft simulation, this is extremely wasteful of memory.

Software. Table 17 compares the various capabilities of the SEL RTM and Interdata OS32MT operating systems. Table 18 is a similar comparison of the SEL FORTRAN IV and Interdata FORTRAN VI compilers.

SEL ranked higher in the evaluation of operating systems. This is due to the fact that the SEL's operating system provides position-independent symbolic global common references and on-line diagnostics that run under the operating system. Without non-ordered, position-independent common area (or datapool), every module and subroutine that references the datapool must be reassembled or recompiled, when the datapool order changes. With position-independent datapool, when the datapool order changes, modules and subroutines that reference the datapool need only be relinked. Thus, the only reason to reassemble or recompile is to make a change to the module itself - not to change a datapool reference or to relocate the module.

SEL's FORTRAN IV compiler also ranked higher for two very important reasons. First, Interdata's FORTRAN VI compiler does not create object code that may then be linked and loaded. Instead, it produces assembly language source code that must then be assembled before linking and loading may occur. This two-step process is not only inefficient, it also creates the possibility that the compiler will not produce error-free assembly code. Second, and more important, although Interdata claims its compiler makes efficient use of machine architecture, this does not appear to be the case. Sperry Systems Management has run FORTRAN benchmarks on both the SEL 32/55 and the Interdata 8/32. The results of these benchmarks (refer to Table 19) have been inconsistent with the calculated throughput data. According to the throughput data, the Interdata 8/32 should execute faster than the SEL 32/55. However, the benchmarks show that the SEL 32/55's times for the thirteen benchmark programs are very close to the Interdata 8/32 times. In fact, the SEL 32/55 actually ran five of the benchmarks faster than the Interdata 8/32. This suggests that the SEL 32/55's slower instruction execution times are compensated for by its more efficient compiler. Conversely, Interdata's compiler makes such inefficient use of the 8/32 architecture, that its compiler loses the time advantage provided by the 8/32's faster instruction execution speeds. The fact that, for each and every benchmark program, the SEL FORTRAN IV compiled programs used less core than did the Interdata FORTRAN VI compiled programs also supports the conclusion that the SEL compiler is more efficient. One may also reason that the same benchmark programs, compiled with the SEL FORTRAN IV compiler and executed on the SEL 32/75, would yield even faster execution times than the 32/55 and would better the 8/32 execution times for more, if not all, of the thirteen benchmark programs.

Table 17. Operating System Capability Comparison

Capability	SEL	Interdata
Event-driven multi-tasking	yes	yes
Simultaneous multiple foreground tasks and a single background stream	yes	yes
Minimum of 30 software priority levels	yes	yes
Interrupt and trap handlers	yes	yes
On-line resolution of external references for foreground tasks	yes	yes
Dynamic memory allocation of foreground tasks	yes	yes
Software and operator task activation	yes	yes
On-line diagnostics run under the operating system	yes	no
Queued I/O	yes	yes
Reentrant task intercommunication and coordination routines available to foreground tasks	yes	yes
Global common memory	yes	yes
Position independent symbolic global common references	yes "datapool"	no
File management and assignment	yes	yes

Capability	SEL	Interdata
Three levels of system generation: 1. Rebuild disc. 2. Alteration of resident OS portions while keeping permanent files intact. 3. Load a fresh copy of resident OS from disc.	yes	yes System generation software functions "tailored to customer needs".
Servicing of all standard peripheral devices	no No paper tape reader handler.	no No Versatek printer/plotter handler.

Table 18. FORTRAN Compiler Capability Comparison

Priority	Capability	SEL	Interdata
1	Efficient use of machine architecture	yes	no
2	Compiler output is object code	yes	no Output must be assembled.
3	In-line coding of intrinsic functions	yes	yes
4	Inter-register transfer of a single argument in a subroutine or function call	yes	?
5	Byte and bit manipulation	yes	yes
6	In-line assembly language code	yes	yes
7	Execution-time error checking during compile	no	no
8	Precise location of errors	yes	yes
9	Expressions containing mixed mode elements	yes	yes
10	Encode and Decode	yes	yes
11	Multiple function and subroutine entry	yes	yes
12	ERR function	yes	yes

Table 19. Benchmark Results*

Program	Core (words)		Time (in seconds)	
	SEL	Interdata	SEL	Interdata
PLASMA	364	508	0.052	0.070
RSTCHK	7646	8140	2.08	2.974
ACOS(X)	358	476	0.090	0.111
ALOG(X)	288	328	0.107	0.990
ASIN(X)	318	436	0.112	0.133
ATAN2(A,B)	228	270	0.060	0.058
ATAN(X)	274	350	0.157	0.131
COS(X)	369	408	0.075	0.067
EXP(X)	278	326	0.065	0.047
A^X	198	228	0.027	0.019
$ALOG_{10}(X)$	158	190	0.042	0.042
SIN(X)	318	380	0.052	0.051
SQRT(X)	281	284	0.615	0.462

*SEL 32/55 benchmarks were run under SEL's RTM (5.0) Operating System using SEL's FORTRAN IV Compiler (REV H) on November 6, 1975, and again on January 6, 1976. Identical results were obtained both times.

Interdata 8/32 benchmarks were run using Interdata's FORTRAN VI Compiler on March 17, 1977.

In conclusion, SEL's software is judged to be superior to Interdata's.

Growth Capabilities. All of the candidate computational systems' primary storage is expandable up to 1 Mbyte with the exception of the SEL 32/75, which is expandable up to 8 Mbytes. The mass storage units can be expanded by adding additional disc drives per controller, up to four for both SEL and Interdata, or by additional controllers and disc drives. The input/output system for both computational systems can be expanded by adding additional logic I/O racks. The processing capacity for either system can be expanded by adding additional CPUs and interfacing via shared memory. The SEL shared memory system will support up to a maximum of 20 computer systems, and each single CPU may access up to six shared memories. The Interdata shared memory system will support up to 14 CPUs.

The SEL 32/75 computer system offers two alternatives to adding additional CPUs. The first is a Writeable Control Storage Option. This option allows microprogrammed (firmware) implementation of user programs, such as math and function subprograms, thereby reducing the CPU utilization by an approximate factor of 4 to 1. The second option is a Regional Processing Unit (RPU). Like the first option it is microprogrammable. Each RPU can be thought of as an extension of the main processor complete with its own arithmetic logic unit, registers, memory, etc. Each RPM is thus a processing node whose local identity, or function, can be assigned dynamically by the main processor for complex content switching, association, content addressing, and similar functions that typically require very high levels of linked parallelism. The Interdata 8/32 system offers only Writeable Control Store.

A synopsis of growth capabilities is presented in Table 20. Clearly the SEL 32/75 has the greatest growth

Table 20. Candidate Computer System Growth Capability Synopsis

	SEL 32/35	SEL 32/55	SEL 32/75	Interdata 8/32
Current Maximum Memory Capacity	1 Mbyte	1 Mbyte	8 Mbyte	1 Mbyte
Current Processor Addressing Capabilities	16 Mbytes	16 Mbytes	16 Mbytes	1 Mbyte
Discs Per Controller	4	4	4	4
Maximum CPUs Per Shared Memory	20	20	20	14
Maximum Amount of Shared Memory	512 Kbytes	512 Kbytes	512 Kbytes	512 Kbytes
Alternatives to Adding Additional CPUs				
WCS	no	no	yes	yes
RPU	no	no	yes	no

potential. The Interdata 8/32 rates second in growth capability, since its WCS option is a more economical approach than that of adding additional CPU's.

Cost Analysis. A cost analysis was performed for two candidate computer configurations that can meet the 100% spare processing time requirements without a multi-computer configuration - the SEL 32/75 and the Interdata 8/32. The total configuration costs are based on the configuration shown in Figure 40. The cost analysis was divided into three areas for closer comparison: they are CPU equipment for all systems, peripheral equipment for first system, and peripheral equipment for all systems. As Tables 21 and 22 show, the total configuration costs for the SEL 32/75 and the Interdata 8/32 are very close, although SEL's cost is somewhat lower.

Vendor software costs, however, are very different, as shown in Tables 23 and 24. All costs are based on the purchase of software provided on 9-track mag tape. Software need be purchased only with the first trainer. Once again, SEL's price is lower, this time however, by 46%.

Survey Conclusion. Since the SEL 32/75 rated higher than the Interdata 8/32 in the areas of throughput, secondary storage, software, instruction repertoire, growth capability and cost, Sperry SECOR recommends the SEL 32/75 as the optimum choice for the AAHT computer system.

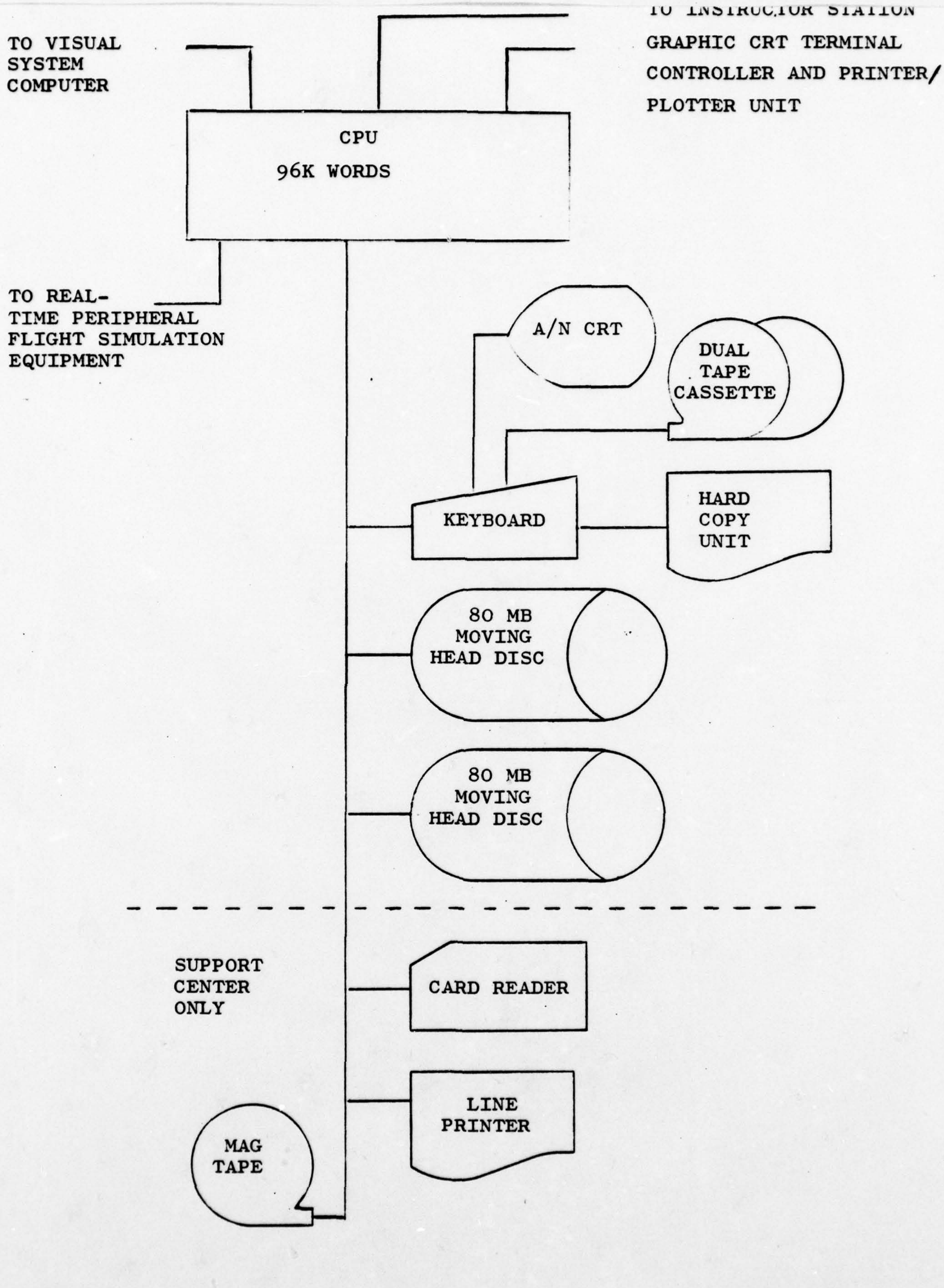

FIGURE 40. AAHT COMPUTER SYSTEM CONFIGURATION

TABLE 21. SEL 32/75 COMPUTER SYSTEM

AAHT CONFIGURATION COSTS

PART A:

CPU EQUIPMENT - ALL SYSTEMS

Item	Qty.	Model No.	Description	Total Price	Total Maint.
1.	1	2312	SEL 32/75 Computer Pkg. w/131,072 bytes of 600 ns core memory.	$ 68,200	$ 470
2.	1	2342	High-Speed Floating Point	6,000	60
3.	1	2345	Real-Time Option Module	2,700	20
4.	1	2142	System Control Panel	3,000	25
5.	1	2145	Hexidecimal Display	600	5
6.	2	2354	Memory Package - 131,072 bytes, 600 ns	34,000	400
7.	1	2336	Memory Carriage Ext. 600/900 ns	3,500	30
8.	1	7410	Analog/Digital Interface RTP	3,500	30
9.	1	9122	Asynchronous Data Set Interface	3,500	25
10.	3	9132	High-Speed Data Interface	12,000	90
			TOTAL	$137,000	$1,150

TABLE 21. SEL 32/75 COMPUTER SYSTEM
AAHT CONFIGURATION COSTS (Cont.)

PART B:
PERIPHERAL EQUIPMENT - ALL SYSTEMS

Item	Qty.	Model No.	Description	Total Price	Total Maint.
1.	2	9762	CDC Moving Head Disc Drive 80MB	$15,400	
2.	2	9010	SEL Moving-Head Disc Controller	10,000	90
3.	1	H2000	Hazeltime Alphanumeric CRT	1,850	
4.	1	4350	Hazeltime Hard Copy Printer	1,900	
5.	1	700	Hazeltime Dual Tape Cassette Unit	675	
			TOTAL	$29,825	

TABLE 21. SEL 32/75 COMPUTER SYSTEM
AAHT CONFIGURATION COSTS (Cont.)

PART C:
PERIPHERAL EQUIPMENT - FIRST SYSTEM

Item	Qty.	Model No.	Description	Total Price	Total Maint.
1.	1	9012	Magnetic Tape Controller	$ 3,500	$ 25
2.	1	9350	Tape Formatter 7/9 Track, NRZI	2,500	15
3.	1	9361	Magnetic Tape Transport	5,000	75
4.	1	9399	Peripheral Cabinet	1,500	-
5.	1	9210	Card Reader - 300 CPM	3,000	55
6.	1	9226	Line Printer - 600 LPM	16,000	200
7.	3	* 73-9406	Card Reader & Line Printer Switch Module	7,200	72
8.	1	* 73-9402	Peripheral Switch Controller	7,000	70
9.	1	* 73-9404-3	Dual Redundant Power Supply Set	3,000	30
10.	1	* 73-9405-1	AC Box	400	4
11.	1	2197	Cabinet for Peripheral Sw.	1,000	-
			TOTAL	$50,100	$ 546

* - Non-Discountable Items.

TOTAL CONFIGURATION COST - $216,925

TABLE 22. INTERDATA 8/32 COMPUTER SYSTEM
AAHT CONFIGURATION COSTS

PART A:
CPU EQUIPMENT - ALL SYSTEMS

Item	Qty.	Model No.	Description	Price	Maint.
1.	1	M83-025	Model 8/32C Processor with 131,072 bytes of 750 ns core memory	$ 51,900	$ 500
2.	1	M83-310	Memory Expansion 131,072 bytes	20,000	180
3.	1	M83-312	Memory Expansion 131,072 bytes	19,500	180
4.	1	M49-035	8/32C System Expansion Chassis	700	-
5.	1	M83-102	Hexidecimal Display Panel	350	
6.	1	M83-111	High Performance Floating Point	6,500	40
7.	1	M83-107	Processor Parity	1,000	-
8.	1	M49-050	50 Amp Power Supply	1,050	10
9.	1	M48-000	Universal Clock Module	750	5
10.	6	M48-050	Buffered Selector Channel	9,000	60
11.	4	M48-013	Universal Logic Interface	700	-
12.	1	M47-102	Programmable Asynchronous Single Line Adapter	500	10
13.	1	M10-054	Data Set Cable	70	-
			TOTAL	$112,020	$ 985

TABLE 22. INTERDATA 8/32 COMPUTER SYSTEM
AAHT CONFIGURATION COSTS (Cont.)

PART B:
PERIPHERAL EQUIPMENT - ALL SYSTEMS

Item	Qty.	Model No.	Description	Price	Maint.
1.	2	M46-600	Model MSM80-67MB Removable Media Mass Storage Module Drive and 1X4 Controller	$50,000	$ 500
2.	1	M46-041	Owl 1200 CRT Terminal	1,995	15
3.	1	M46-044	Printer Port for RS232C	95	-
4.	1	M46-060	Carousel 30	2,475	35
5.	1	M46-024	Current Loop Interface for Carousel	400	5
6.	1	M46-400	Intertape Cassette System	4,200	40
			TOTAL	$59,165	$ 595

TABLE 22. INTERDATA 8/32 COMPUTER SYSTEM
AAHT CONFIGURATION COSTS (Cont.)

PART C:
PERIPHERAL EQUIPMENT - FIRST SYSTEM

Item	Qty.	Model No.	Description	Price	Maint.
1.	1	M48-014	I/O Bus Switch	$ 1,700	$ 20
2.	1	M48-018	Manual Control Panel for I/O Bus Switch	200	19
3.	1	M46-235	Card Reader Interface	990	10
4.	1	M46-238	400 CPM Card Reader	3,060	40
5.	1	M46-206	Line Printer Interface	990	10
6.	1	M46-209	600 LPM Line Printer	17,150	110
7.	1	M46-494	9 Track, 800/1600 Dual Density, 75 ips Magnetic Tape System with Controller	24,000	220
8.	1	M49-040	System Cabinet	925	-
9.	1	M49-041	AC Distribution Panel	-	-
			TOTAL	$49,015	$ 429

TOTAL CONFIGURATION COST - $220,200

TABLE 23. SEL COMPUTER SYSTEM SOFTWARE COSTS

Item	Qty	Model Number	Description	Price
1.	1	599-321001	Real Time Monitor (Source)	$1,500
2.	1	519-321001	Real Time Monitor (Binary), Macro Assembler Included	750
3.	1	519-321012	FORTRAN IV (Binary)	250
4.	1	599-32103X-XXX	All Off-Line Diagnostics (Source) 22 @ $35 each	770
			TOTAL	$3,270

TABLE 24. INTERDATA COMPUTER SYSTEM SOFTWARE COSTS

Item	Qty	Model Number	Description	Price
1.	1	S90-006-X1	OS/32MT (Source and Object)	$5,000
2.	1	S90-213-X1	FORTRAN VI (Object)	500
3.	1	S90-20S-X1	CAL Macro Processor (Object)	450
4.	1	S90-405-X6	Multimedia Diagnostic (Object)	100
			TOTAL	$6,050

INTERFACE SYSTEM

The interface system, which is the focal point of all system hardware, should be designed so as to provide ease in maintenance as well as to be easily programmed to access any or all channels of a particular type of I/O.

Computer access to the interface should be via a random or a block transfer. Both of these methods are required to allow the programmer the most flexible means of transferring data to the interface. Block transfers are the most commonly used in today's trainers because of the computer time required and the ease in programming. Since the latest generation of computers allows the transfer of data without cycle-stealing time, it is logical to set up the I/O transfer once for a large block and to continue the execution of the simulator programs. However, during maintenance and occasionally in the simulator software a need arises to access one device in the I/O without affecting the other devices. As a result, random access would be required to perform this task. This feature is very important when the interface has a failure in its control logic. The operator, by setting up a single transfer, will be able to diagnose a problem without concern about other transfers being made.

For testing the interface, a closed loop I/O test should be provided that checks each discrete and each channel over the range of the particular channel. Discrete inputs should be checked individually in both the high and low states. After testing of the discrete inputs, a test should be run on the discrete outputs. This test would toggle the discrete outputs from one state to another. The output of the discrete outputs would be routed to a corresponding discrete input that has been automatically disconnected from its regular trainer input.

Analog testing should be done in such a manner that the full voltage swings of the analog devices are tested. The analog input testing should test at least three different voltage levels. Likewise, analog output testing should be done using at least three different voltage levels and should be routed for testing through existing analog inputs.

Synchro testing should include the testing of the synchro converters through the range of the converter. The testing of all converters should be under computer control and all switching should be controlled by the computer.

The interface system should be designed in such a manner as to have as much noise immunity as possible. Analog inputs and outputs should be required to have differential inputs and outputs respectively. Twisted pair lines for the analog signals should be used.

It is recommended that a commercially available interface system not be used for the AAH simulator. Some of the reasons behind this are:

- I/O contains many features that cannot be used in a simulator.
- I/O test is difficult to perform.
- Equipment is unneccessarily large.

Most commercial interface systems are designed to interface with several different computers, with each computer system having its own requirements. As a result of trying to manufacture an interface applicable to most needs, the interface manufacturer has built in many features that are never used by a simulator manufacturer but are paid for by the customer.

The needs of I/O testing as described previously do not lend themselves to a commercial interface. In order to

facilitate such a test condition, all interface signals would require routing through an array of relays, such as T Bar. This leads to many more solder and crimp connections and more wire, resulting in a higher probability of noise susceptance and a more difficult system to maintain.

For the above reasons, the commercial interface requires considerable equipment occupying several cabinets. This problem can be alleviated by having an interface specifically designed for a simulator.

An interface system designed for a simulator's needs requires very little space. The I/O testing for digital and analog equipment can be performed on the individual board rather than going through relays, etc. This is accomplished by having standard analog boards and standard digital boards versus having standard analog input, analog output, digital input, and digital output boards. These boards would contain, for example, one digital input word and one digital output word. The boards would contain all the necessary hardware for self test. Discrete outputs would be of two types: (1) a high speed TTL device for interfacing with other TTL hardware, and (2) slower transistor switching with a higher output current. The slower switching devices would be used for interfacing with lights, relays, etc., where fast switching speeds result in high noise levels.

Another feature that should be incorporated into an interface is an analog output memory. Due to occasional halts of the computer, either intentional or non-intentional, the sample and hold capacitors discharge themselves, resulting in instruments and other analog driven signals changing. The solution is to incorporate a memory which allows the sample and hold to be updated, regardless of whether the computer is running. This will prevent any

droop in the analog output voltage, which in turn could put an undesired voltage on an instrument, amplifier, etc., unless additional switch circuitry is used.

WEAPON DELIVERY SYSTEMS

The visionic gear located in the cockpit and gunner stations is the principal equipment used in weapon delivery. The equipment provides a feedback for the gunner and pilot for aiming his selected weapons. The heart of this equipment is the fire control computer (FCC) with the Hellfire missile system, IHADSS, TADS, PNVS, and Doppler system providing and receiving data from the FCC and each other.

Fire Control Computer

The fire control computer performs computations necessary for target acquisition and weapon ballistic compensation, and supplies logic commands required to control the fire control subsystem. The computer provides both azimuth and elevation aiming information for the 30mm gun, Hellfire missils, and the 2.75-inch rockets. The aiming point prediction is based upon information from the laser or manually-selected range, TADS, helmet or direct sight angles, air data and aircraft flight parameters, targeting-navigation geometry, and weapon/projectile ballistics.

The fire control computer used in the aircraft is a 16-bit, parallel, general purpose computer. The memory capacity of the computer is 16K words of random access, non-volatile, read-only memory, and 2K words of random access, volatile, scratch pad memory. The memory speed is approximately one microsecond.

The interface for the on-board computer is housed with the computer. The interface receives as a minimum the following types of signals:

Inputs	
Discrete	18
Synchro	3
DC Analog	7
Digital Serial	3
AC Reference	1
Mux Data Bus	2
Outputs	
AC Analog	5
DC Reference	1
Discrete	2
Digital Serial	1
Mux Data Bus	2

The Mux data buses are multiplex data channels per MIL-STD-1553. They are capable of communicating with up to 32 devices.

In the simulator there would be three alternative ways of simulating the fire control computer. These three ways are (1) using the on-board computer, (2) emulating the on-board computer program, or (3) generating a compiler so that the on-board computer program can be loaded into one of the simulator's computers. The advantages and disadvantages of each should be studied in detail before any requirement is stated in the trainer specification.

Trainer-Peculiar Features

A trainer, because of its need for versatility, has many features that create problems when aircraft parts, especially on-board computers, are used. Some of these features are Freeze, Reset, Playback, Failures, and Demonstrations.

When an on-board computer is used, problems arise

concerning how to stop the computer from executing any of its program for a period of time but to allow the computer to continue to send the last computed results at "freeze" to the various equipments. This process can be accomplished by modifying the aircraft program for the simulator, but it defeats the main reason for using an on-board computer, i.e., having the capability of keeping the computer program up to date.

With a compiler method, "freeze" would require in the program executive a means of executing only the output transfer and not executing any other portion of the program. This method would be fairly simple: the I/O routine for the on-board program would probably not be called in a compiler method of simulation because of each computer having its own trainer-peculiar I/O. As a result, the I/O would be under control of the simulator executive, not the on-board computer executive.

An emulated program is an ideal solution for the "freeze" problem because all operations are totally controlled by the trainer executive. The programs can be modeled to include all of the features previously mentioned (Freeze, Reset, etc.).

Record/Playback, Demonstration, and Reset to a specific point all create similar problems when the on-board computer is used. The main difficulty is the method of programming the computer back to a particular point in time. This problem is handled in the emulated and compiler methods of simulation by storing all flags and past values required on the disc. The problem would be more difficult with the compiler method but could be solved. Normally there is no way of solving this problem when using the on-board computer. If the training exercise did not require the

fire control computer to reinitialize to a particular point, the problem would be eliminated altogether. But, with all the systems that are controlled by the fire control computer, much would be lost without this feature.

The last problem to be dealt with in trainer-peculiar features concerns failures. One of the great advantages of trainers is to teach the student first how to recognize a failure and secondly how to accomplish the required corrective actions. If an on-board computer were used, all failures dealing with the computer would have to be examined carefully to determine whether or not they could be accomplished and still obtain all of the proper indications. Since many signals go over the MUX bus and serial data lines, a large number of possible failures would be very expensive or impossible to implement with an on-board computer. With a compiler or emulator method, many failures, if not all, could be simulated by incorporating them in the I/O routine or, in the case of the simulation method, in the computer software.

As a result of the above discussion on trainer-peculiar features, it can be concluded that the best simulation of the fire control computer is by emulation. This method will allow the greatest flexibility and the least risk in solving the problems described. The compiler method will allow many of the problems presented to be overcome, but the risk in being able to solve all of the problems must be considered as medium at best. High risk would be to use the on-board computer and expect to get all of the trainer-peculiar features. This method is considered the undesired approach for these features.

Software Updating

When an aircraft fire control computer is used in a

simulator, one of the major problems is how will the simulator computer program be kept up to date with the aircraft computer program. This problem is often not examined closely enough to prevent degraded training from occurring. With a new computer being developed for a new aircraft, at least three major revisions will normally be made to the aircraft computer software between trainer design freeze and acceptance. The result is an out-of-date trainer when it is supposedly ready for training, and a trainer that is difficult to test because of inability to define the computer program as it existed at the trainer design freeze date. This situation is normally encountered when emulating an on-board program. When using a compiler method of simulation, the program can be kept up to date by loading the new aircraft tape if the locations of program calls and the data pool have not been changed. If the on-board computer were used, the tape could immediately be loaded and run. The only problem that could occur then would be hardware additions. This problem, however, would affect all types of simulation and would require action in any case.

It can be concluded that the best method for keeping the fire control computer up to date is to use the on-board equipment. By using the compiler method, a risk would be incurred that some other programs might have to be changed in order to update the basic program. Such changes, however, should not require a major effort. The emulation method is the most costly in terms of keeping the system up to date and could result in the system being far behind the aircraft. If this method were used, Sperry SECOR would recommend that means be developed to allow program changes to be incorporated as soon as required, and that the software for the fire control computer be

designed so as to allow fast incorporation of changes.

Monitoring Controls and Displays

In order to fulfill his role in training, the instructor must know what the student pilot and gunner are doing. To obtain information on how the student is performing in operating his fire control computer and associated equipment, the instructor must have knowledge of what the student's mission is, what he has done, what he is currently doing, and what he is seeing. This requires the instructor to, in some way, be capable of monitoring all switches and control panels associated with the fire control computer. This requirement applies whether the instructor is positioned behind the student or at a remote station. Provisions must be made, preferably by a CRT display, to monitor this information. If the instructor is behind the student, he must be provided full monitor capability including displays and switch settings that could very easily not be visible from the instructor's position.

When the fire control computer is simulated for emulation this problem is easily resolved. The simulation computer needs to know all of this data to perform its computations, hence, the data is already available in a usable form. The same condition exists for the compiler method of simulation, since all of the inputs and outputs are generated in the simulator computer. The use of an aircraft computer, however, creates several problems. One problem is how to obtain the switch settings that are being transferred over the MUX bus. This problem can be solved but requires more hardware than normally would be required. One solution is to provide a repeater readout, employing additional hardware to pick up the data and

decode it. If processing is done in the terminal unit, this also would have to be duplicated. Another problem is to provide a readout to the instructor on what is being displayed on the computer terminal, and to allow the instructor to look at other parameters not selected for display by the student. This last aspect, i.e., providing a readout of various data in the fire control computer regardless of student selection, cannot be overcome unless the fire control computer is modified. This would then defeat the purpose of using the on-board computer.

Conclusions regarding this particular problem are that either emulation or compiling are the preferred methods to simulate the fire control computer. The use of the actual computer would sacrifice to some degree the training effectiveness of the trainer and would require additional hardware.

Interfacing

Many fire control computers have complicated interface requirements, especially when they are used to control and receive data from an inertial measurement system. However, the interface requirements for the AAH aircraft fire control computer do not appear to be extensive or complicated. This should result in easy interfacing with the on-board computer if it were used. Likewise, interface requirements when simulating the fire control computer by the emulation or compiler methods do not appear to present any problems. Most of the data is already in the simulation computer; so, in fact, the I/O requirement is reduced from the on-board computer method.

One other problem, timing, is encountered in terms of interfacing with the on-board computer or by compiling the on-board program. Although timing is not considered a

difficult problem to solve, it can be very expensive. A fire control computer's iteration rate is normally much faster than the simulation program's fastest rate. This means that, to avoid any anomalies that might occur because data seen by the on-board computer program is not being updated fast enough, many modules will require a faster iteration rate. As a result, this will increase the number of computers required for the simulation problem.

Based on the above discussions, it is evident that advantages and disadvantages can be found regarding the various ways to simulate the fire control computer. Much weight should be placed on how the trainer will be affected in its training capability. Also, one should look at the total cost to determine the cost effectiveness, and include in this cost impact due to keeping the trainer at the same level as the aircraft. With all of the factors mentioned and realizing the requirements that must be met to accomplish the training mission of the AAHT, Sperry SECOR recommends that the fire control computer be simulated by compiling the on-board program into a language suitable for use in the simulator's computer. This method would allow the trainer program to be kept up to date at a reasonable initial cost. All the problem areas mentioned in this discussion have little impact on the trainer if the compiler method is used.

Visionics

The visionic equipment associated with the fire control system are the Target Acquisition and Designation System (TADS), Pilot Night Vision System (PNVS), and the Integrated Helmet and Display Sight System (IHADSS). A fire control symbol generator is used to produce the

symbology for the pilot and copilot integrated helmet display system and the copilot's direct view display. Video from the TADS TV, TADS FLIR, PNVS IR, video recorder, and missile infrared imaging seeker (when installed) is also supplied to these systems.

Simulation of the visionics equipment should be accomplished via the visual system, specifically through the CGI processor. A single processor channel would drive the simulated TADS displays used by the gunner. Two CRTs would be connected to the same video input. One would act as the gunner's panel CRT. The other would be observed through the gunner's TADS eyepiece. For normal viewing distances, the panel CRT subtends about 20° in the gunner's vision, while the eyepiece shows him a 64° field. Thus, magnifications are different for the two displays, as summarized in the chart earlier in this section.

The pilot's only CRT display is through his helmet-mounted display, which normally will carry the IR from the PNVS for night operations. Both the pilot's and gunner's helmet-mounted display can show any TADS or PNVS video at their selection, but only the IR data shows at unity magnification in this display. A fire control symbol generator is integrated with the video chain to the visionics to produce symbology for weapons status and control. The Hellfire missile Infrared Imaging Seeker (IRIS) video can also be selected for display.

The TADS/PNVS sensors and the gunner's panel displays would thus be simulated with CRTs and optics, while the IHADSS could be stimulated by the visual and computer modules. The integration of the visionics with the windshield would allow the crew to correlate their views in a way that implements the full mission training requirements of the AAH-FWS.

All weapons that the AAH can carry should be included in the AAHT. This would include the gun, rockets, and Hellfire missile. The simulation should provide operational training for all weapons in all modes. For the Hellfire missile, the instructor should be given the capability of acting as the illuminator. Failures, such as missfires, should be provided.

RELIABILITY AND MAINTAINABILITY

Introduction

The primary objective of reliability and maintainability programs for simulator devices is to maximize total system availability for training during the projected usage.

This section of the study addresses the reliability and maintainability requirements for the FWS, and provides definitions, discusses program management and recommended R&M tasks, and presents initial MTBF and MTTR prediction estimates and conclusions.

Definitions

Reliability is defined as the probability that an equipment will continue to function correctly for a specified period of time without failure under a prescribed condition of use. Maintainability is an expression of the probability of equipment being restored to operating status within allowable time limits using available test equipment, facilities, trained personnel, spare parts and procedures (texts).

R&M Program Management

Reliability and maintainability are listed as Integrated Logistic Support (ILS) elements (ref: NAVTRAEQUIPCEN Bul. 40-1) from the standpoint of their maintenance preventive roles. However, both remain as functions of design to permit engineering apportionment of performance goals to subsystems and components. Since reliability and maintainability have a direct influence on operational availability, they must be considered strongly in equipment readiness, performance and cost effectiveness trade-offs. Surveillance over changes in both design and support is required to prevent degradation.

Trade-offs are conducted to improve system design and support and to provide a continual narrowing down of initial configuration designs and ideas until a firm production baseline is established.

<u>AH-64 FWS Program Tasks</u>

Major reliability and maintainability tasks to be included in the AH-64 FWS program are listed below. Although the overall responsibility is assigned to ILS, many inputs will be required from other interfacing disciplines such as design and systems engineering, standardization, human and safety engineering, etc.

<u>Task</u>

- Organization Implementation - Contractor
- Interface Compatibility - Design Configuration
- Subcontractor and Vendor Compliance - R&M Programs
- Establish R&M Data Collection System
- Parts Testing - Stress Analyses
- Failure and Repair Time Analyses
- Program and Design Reviews
- Contract Formal Reports - DD Form 1423 (CDRL)
  R&M Program Plans
  Quarterly Status Reports
  Test and Demonstration Plans and Reports
- Establish Formal Prediction Model and Goals
- Conduct Reliability Test
- Maintainability Demonstration (on site)

<u>AH-64 FWS Prediction Model</u>

Figure 41 is the initial reliability and maintainability prediction model for the major system model areas

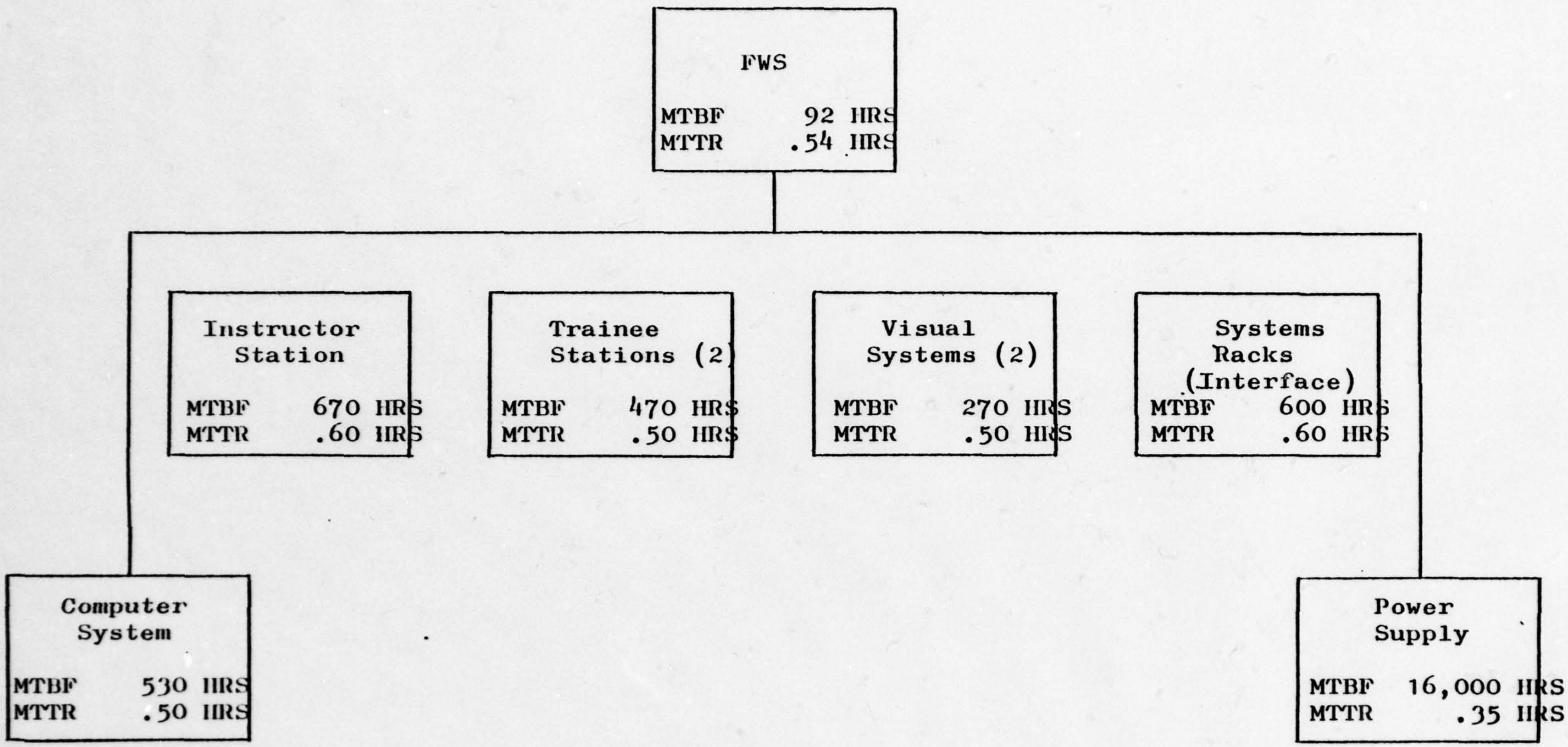

Figure 41

AH-64 FWS Initial System Prediction Model

of the FWS. The model is serially arranged in a "family tree" format. The model was developed from the design and configuration concepts contained in this study and is based on the following R&M data sources:

- Vendor supplied
- Sperry SECOR experience
- MIL-HDBK-217B
- MIL-HDBK-472

Current predictions indicate a 92 hour MTBF, and a .54 hour MTTR. Inherent availability is .9942.

It is planned during the final report and specification preparation to further detail the model to include identification of the major subsystem areas. Any changes resulting from this refinement will be incorporated in the final report and detailed specification.

Conclusions

The AH-64 FWS design essentially is based on existing state-of-the-art technology and proven Sperry SECOR designs and designs of potential sub-contractors. This lends confidence in the quantitative reliability and maintainability estimates as established in the initial system model. Further, these initial estimates have been compared with actual values resulting from tests and demonstrations on comparable equipment configurations as that proposed for the AH-64 FWS. In these cases there has been very reasonable agreement between the predicted and actual values.

INTEGRATED LOGISTIC SUPPORT

Introduction

Integrated Logistics Support (ILS) is a concept designed to ensure that equipment delivered to the field can be adequately and efficiently supported for its expected useful life. ILS is defined by NAVTRADEVCEN Bul. 40-1A as "a composite of the elements necessary to assure the effective and economical support of a system or equipment at all levels of maintenance for its programmed life cycle."

The following paragraphs present in summary form the objectives, elements and management requirements of an ILS program. Discussions pertaining to ILS are based to a large extent on past and present contracts with NTEC.

ILS Objectives

The objectives of an Integrated Logistics Support program are twofold:

- To ensure completion of the logistic support items on schedule
- To ensure that the logistic support items are adequate to fulfill their intended purpose.

Both objectives must be accomplished to provide adequate support for the device once it has been delivered.

To accomplish the first objective, two conditions must be met. The first is the availability of sufficient manpower to accomplish the required task within the time allowed. The second is the availability of sufficient input information from the design group early enough in the program to permit the task to be completed on schedule.

The availability of sufficient manpower is an administrative problem which requires a complete under-

standing of the effort required to accomplish the work and the ability to forecast the number and types of people which must be made available during the program. Top management is responsible for ensuring that these personnel needs are satisfied.

The second objective of the Integrated Logistic Support program - to ensure that the support items are adequate to fulfill their intended purpose - also requires that two conditions be met. First, the personnel engaged in preparing the items must be competent and experienced. Second, the support items must be accurate and must reflect the device exactly as delivered. This condition is the most difficult to achieve and can only be accomplished with a strong, comprehensive logistic support program coupled with a rigorous drawing control procedure and quality assurance program.

ILS Program Elements

In general, an ILS program for a simulator system consists of the following major areas:

- Reliability
- Maintainability
- Standardization
- Technical Publications (O & M Hdbk, PMS, etc.)
- Provisioning
- Contractor Conducted Training
- Support Equipment
- Spares/Repair Parts
- Interim Support
- Subcontractor and Vendor ILS Compliance

These program elements are further iterated in logistics support analyses and life cycle costs conducted throughout the program period.

ILS Program Implementation and Management

Program implementation and management are assigned to a logistics coordinator or logistics manager to insure overall control and achievement of the ILS tasks. The Integrated Logistic Support Management Plan (ILSMP), a contract deliverable report, is a comprehensive plan fundamental to the management and execution of the ILS program. Milestone schedules which are an integral part of the Plan interrelate both contractor and Government activities which are necessary to accomplish the required logistics support contract elements on schedule. The ILSMP is reviewed and monitored on a regular basis to identify or forecast progress and/or possible slippages. Formal presentations and discussions of ILS program status are accomplished during progress reviews. Problem areas, if any, are identified and resolved at these times.

ILS Requirements and the AH-64 FWS

An ILS program on a future AH-64 FWS procurement contract will require detailed planning and coordination in meeting the necessary support requirements. This is based both on size of the simulator system and equipment complexity. However, no major problems are envisioned in the ILS areas since a large portion of the equipments are commercially available or of proven design for which ILS related data is readily (or near readily) available.

SECTION V

ANALYSIS OF OPERATING CHARACTERISTICS

This section of the study addresses the operating characteristics of the AH-64 FWS, i.e., the simulation of aerodynamic motion and engine operation, and the design and capabilities of the instructor station. Conclusions are made regarding possible approaches to mathematical models for aerodynamic and engine simulation; and regarding the controls, displays, and instructional programs considered to be optimum for the AH-64 FWS.

AERODYNAMIC AND ENGINE SIMULATION

Aerodynamics

Appendix A presents a complete equation set for simulation of a helicopter motion. The appendix is based on the Sperry-SECOR Specific Response Approach (SRA) to rotor simulation. Much of the equation development, however, applies as well to other approaches in common use and underlies the discussion of the differences among models, which follows.

Mathematical models of helicopter motion differ from each other primarily in their description of the main rotor system. Most current rotor simulations take the modified blade element (MBE) approach, the coefficient approach, or the approach typified by the Sperry-SECOR Specific Response Approach (SRA). All three approaches are founded on developing expressions for the forces and moments acting on a rotor-blade element, the element being defined as an airfoil segment at polar coordinates r, ψ. Here r is the radial distance of the element from the center of rotation along the blade axis and ψ is the azimuth angle with respect to a reference axis.

Where the approaches differ is in the method of proceeding from the blade-element quantities to the total forces and moments of the rotor.

In the MBE model, for which the theoretical basis is given in Reference 1K, blade element forces and moments are computed at i radial distances $r_1, \ldots, r_i$ at each of j azimuth angles $\psi_1, \ldots, \psi_j$. *The force or moment on the rotor* blade at azimuth angle ψ_j is then computed by a numerical integration scheme, which derives it as a linear combination of the quantities at the i radial stations. For example, the thrust (lift) T_{ψ_j} at azimuth angle ψ_j is computed as

$$T_{\psi_j} = \sum_{n=1}^{i} k_n \; T_{\psi_j}, r_n$$

where the k's are coefficients of the numerical integration scheme. With the force or moment on the blade at each of j azimuth angles known, integration around the azimuth is effected by a linear combination of the j quantities; e.g.,

$$T_{total} = \sum_{m=1}^{j} k_m \; T_{\psi_j}$$

The computation of the i X j blade-element quantities, and the integrations along the blade and around the azimuth, are done in real time in the MBE approach. Consequently, for computation efficiency, the number of radial stations and azimuth angles should be the minimum consistent with the accuracy required of the simulation. A recent NASA study (Reference 2K) recommends that no fewer than three radial stations and three azimuth angles be used in the simulation of an articulated single rotor system.

The coefficient approach on the surface is markedly different from the MBE. It bears a closer resemblance to

fixed-wing simulations in that dimensionless coefficients of forces and moments are obtained by interpolation in data tables in computer memory. The data tables, however, represent the output of an off-line program (the so-called "Truth Rotor" program) which incorporates a rotor model that is basically the same as the MBE model. The principal difference is that a much higher number of radial stations and azimuth angles are used, typically 30 radial stations and 72 azimuth angles. With the increase in the number of computed blade-element values, errors in integrating along the blade and around the disk are reduced. Furthermore, since the computations are done off-line, no penalty in computing time is paid for the increased accuracy (provided an efficient interpolation method is used). Computer storage is another matter: the data tables alone may require several times the storage of the MBE model. In a model using the coefficient approach, rotor thrust T might be computed as

$$T = k\sigma\Omega^2 C_T$$

where k = constant depending on rotor geometry

σ = air density ratio

Ω = rotor angular velocity

$C_T = f(\mu, \lambda, \Theta_E)$

μ = ratio of airspeed to blade-tip speed

λ = ratio of in-flow velocity to blade-tip speed

Θ_E = effective blade pitch angle (dependent on collective stick setting)

The function of $f(\mu, \lambda, \Theta_E)$ might be represented by a three-dimensional table in computer memory, and C_T calculated by interpolation. Alternatively, C_T might be factored into a form such as:

$$C_T = f_1(\mu, \lambda) + \Theta_E f_2(\mu, \lambda)$$

The two functions would then be stored as two-dimensional tables and the coefficient computed by interpolating twice and then evaluating the algebraic expression for C_T.

The Specific Response Approach (SRA) is characterized by a set of equations which describe helicopter rotor performance and reaction by directly computing the composite rotor forces and moments. With certain simplifying assumptions (see Appendix A), the expressions for blade-element quantities are integrable along the blade and around the disk; that is, equations of the form

$$T = \frac{1}{2\pi} \int_0^2 d\psi \int_0^R dT$$

have analytical solutions. The simulation equations for thrust, flap angles, in-plane forces, and induced and profile torque can be derived from such equations. To continue with rotor thrust as an example, the simulation equation would be

$$T = \sigma \Big[\Theta_E \; (k_1 \Omega^2 + k_2 \; V_{xy}{}^2) + k_3 \Omega (W - W_{i_m} - U \; B_{1S} - V \; A_{1S}) + k_4 \; (pU + q_1 \; V) \Big] \quad f \; (L_{ss})$$

where σ = air density ratio

Θ_E = effective blade pitch angle

Ω = rotor angular velocity

V_{xy} = airspeed in X-Y plane of reference axis system

U = airspeed along X axis of reference axis system

V = airspeed along Y axis of reference axis system

W = vertical velocity (along Z axis of reference system)

W_{i_m} = mean induced vertical velocity

B_{1S} = longitudinal swashplate angle

A_{1S} = lateral swashplate angle

p = roll rate, reference axis system

q_1 = pitch rate, reference axis system

L_{ss} = length of slipstream (used to introduce ground effects)

and the k's depend on rotor geometry.

In contrast to the MBE approach, the SRA model requires neither real-time computation of incremental variables nor the application of a numerical integration scheme to arrive at total forces and moments. In comparison with the coefficient approach, it offers continuous solutions and low computer storage requirements. It differs from both approaches in that it depends on the mean induced velocity rather than on local induced velocity. The MBE real-time program, and the off-line ("Truth Rotor") program of the coefficient approach, both depend on defining the local angle of attack, that is, the angle of attack of the *blade element*. The local angle of attack, in turn, depends on local induced vertical velocity. Although any of several in-flow velocity distributions over the rotor disk (References 1K and 3K) can be assumed in attempting to develop a rotor simulation, no definitive simulation equation has been derived. Mean induced velocity, on the other hand, can be derived with a high degree of accuracy from momentum theory.

All three approaches -- MBE, coefficient, and SRA -- are being used successfully for rotor simulation. The MBE is used in a number of helicopter training devices built in the 1960's; it is also the basis of the rotor simulation currently used in helicopter studies on the RTS (Real-Time Simulation) system at Langley Research Center, NASA (Reference 4K). Helicopter flight training devices built in the 1970's

use either the coefficient or the SRA method. Sperry-SECOR prefers the SRA method, which it developed and which is currently used in real-time simulations of more types of helicopter (HH-3F, HH-52A, CH-3E, HH-53C, and TH-1L) than any other method. However, another simulator manufacturer, throwing into the balance such factors as model characteristics, computer system capacity, support software, and -- in particular -- in-house expertise, might well have a different preference. So long as the design is carefully constructed, any of the three approaches can lead to an aerodynamic model within the accuracy requirements of the AAHT.

Engines

Simulation of turboshaft engine performance and dynamic response, to a high degree of accuracy, is within the state of the art of real-time modeling techniques. Sperry-SECOR recommends that the structure of the engine model be analagous to that of the engine/fuel control system. While other model structures may reproduce normal engine operation with equal fidelity and efficiency, the system analog simplifies malfunction simulation. It permits many of the malfunctions to be inserted at only one entry to the model, yet produce the expected results on all affected engine variables. With other model structures, it is often necessary to force malfunction reactions on each affected variable individually.

Figure 42 shows the relationships among variables in a typical math model of a turboshaft engine, the model structure being analagous to the aircraft system. Also shown are entry points for some of the malfunctions that might occur while the engine is in the normal operating range (idle or above). The key to the numbered malfunctions is as follows: 1) engine surge; 2) flameout; 3) turbine temperature high; 4) engine

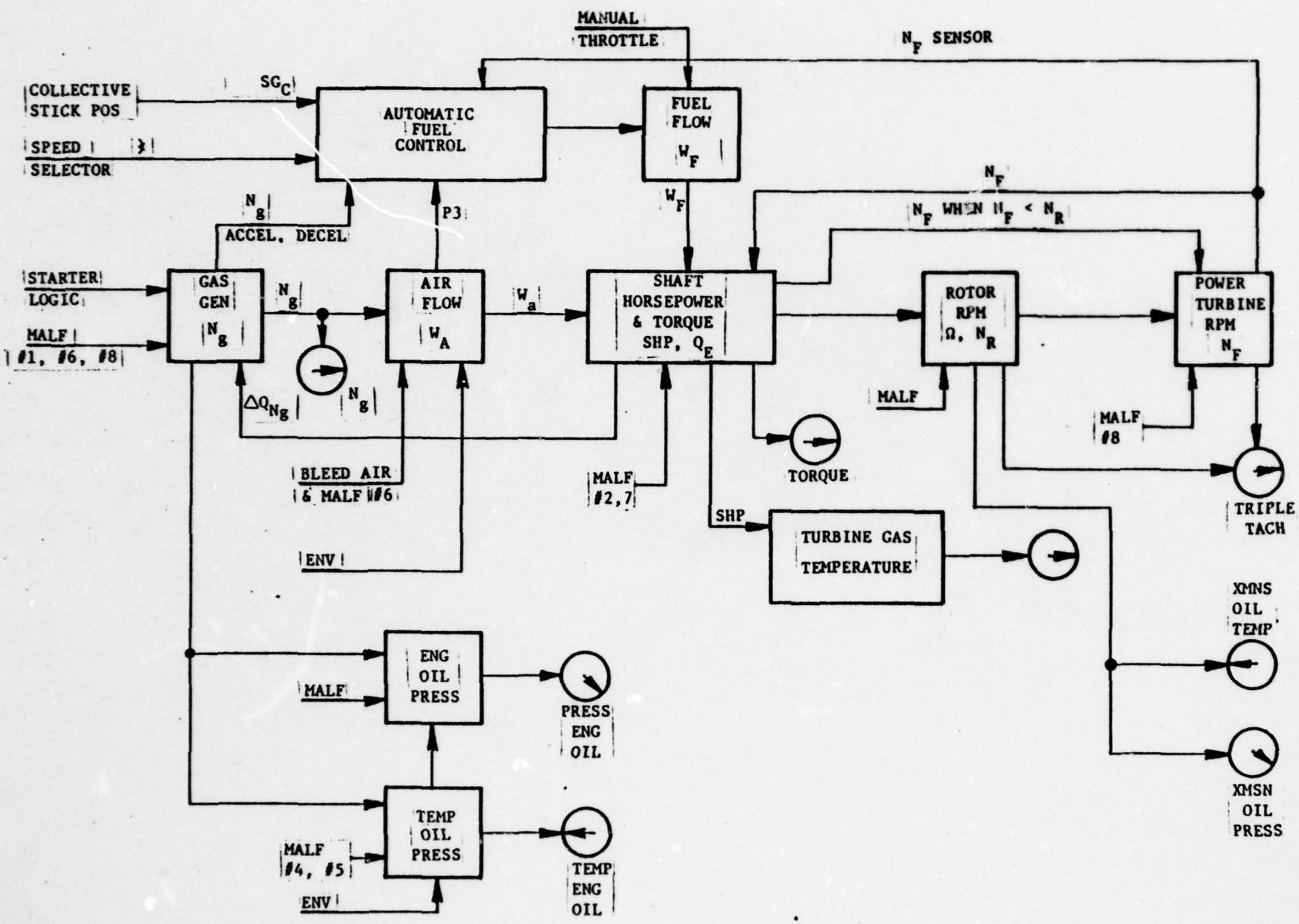

FIGURE 42. ENGINE COMPUTATIONAL SYSTEM

oil temperature high; 5) engine oil temperature low; 6) engine icing; 7) torque gauge fluctuations; and 8) tachometer failure. The surge malfunction is an example of one that affects many engine variables but that, in an analog-structure model, needs to be inserted at only a single point.

INSTRUCTIONAL SYSTEMS

For the purpose of this study, instructional systems are defined as those equipments and computer programs intended to assist instructors to perform their training tasks with the simulator. Instructional systems include the instructor station controls and indicators, CRT's and displays, input devices, and various computer programs to initiate and control training exercises, introduce malfunctions, monitor student performance, and otherwise provide or assist instruction.

Generally, instructional systems may be divided into two broad categories: hardware and software. There is an obvious interrelationship between the two, since the controls and input devices in the trainer are usually designed to operate or implement software programs.

Controls

The controls at an instructor station can include momentary, alternate, or latching action push-button switches that may be illuminated or non-illuminated; rotary controls to vary the intensity of effects; slew switches to make uni-directional changes in aircraft flight conditions; and joystick controls to make multi-directional changes. Push-button switches can be grouped together for a common purpose, such as in an alphanumeric keyboard or a function keyboard.

Some specialized controls are sometimes referred to as input devices, particularly when their purpose is to enter digital data into the computer. Alphanumeric keyboards can be considered to be in this category. Such a distinction is not very useful in a modern trainer, however, because virtually all instructor station controls operate through a digital computer.

The extent to which any type of control is used in a trainer can be either left to the contractor's option or prescribed, in various ways, in the specification. It is considered that if any type of control clearly has advantages over other types that could be used to perform a given function, the preferred type should be specified. This conclusion is based on the premise that the cost of the preferred type will be within a range of acceptable or reasonable costs for such items. The rationale behind the conclusion is that the Government should insure that it will receive a desired level or quality of trainer performance. Being as explicit as possible in the trainer specification will decrease the risk of a contractor using approaches or equipments that reduce costs at the expense of trainer performance.

The following is an analysis of the advantages and disadvantages of using in the AAHT each type of potentially available control.

Alphanumeric Keyboard. An alphanumeric keyboard, for the purpose of this analysis, is a standard typewriter-style keyboard with a full range of letters, punctuation marks, and numerals. It is normally provided by CRT vendors as an input device. Sometimes special keys are provided for functions such as RUB OUT, LINE FEED, etc. By the use of upper case keys, a wide range of symbols can be available for programming graphic displays.

Whether an alphanumeric keyboard is needed on any trainer depends on the quantity and type of data to be entered into the computer and on the philosophy of formatting inputs. Device 2F108, an A-4M OFT build by Sperry SECOR, is an example of strong dependence on an alphanumeric keyboard.

Almost all inputs are made by the instructor calling up a page on the CRT (by typing the letter P and the page number) and then entering the data via a line number which appears on the CRT page. For example, to add fuel to the fuselage tank, the instructor calls up the page entitled FUEL, OXYGEN, EMER CONTROLS, and types the letter I (a code for "input"), the number of the line that reads FUS QTY (line 01 in this case), a comma, and the total number of pounds of fuel desired. To refuel the tank to 1500 pounds, the entry will be "I01,1500." The entry appears on the CRT on an edit line where the instructor can inspect it for accuracy; it is entered into the computer by the instructor using the carriage return key.

A number of yes-no or on-off functions, which on other trainers are accomplished with push-button switches, are accomplished in Device 2F108 with the alphanumeric keyboard. The number 1 is entered for the true state and 0 for not true. For example, to program icing conditions, the instructor first displays the INITIAL CONDITIONS, ENVIRONMENT page, then enters the number 1 in line 28 which is entitled ICING. The entry is "I28,1." To later remove the icing condition, he types "I28,0." Other on-off functions accomplished with the alphanumeric keyboard include starting the mission clock, loading the internal guns and chaff dispensers, installing and removing wheel chocks, engaging the probe/drogue in inflight refueling, and resetting the emergency generator and manual flight controls after employment in a simulated emergency.

In Device 2F108, only five letters (P for "page," I for "input," F for "failure," D for "delete," and R for "repeat") are used in input codes, but most of the

remaining letters are used to enter the identification letters of programmed radio facilities.

Device 2F119, an EA-6B WST built by Sperry SECOR, is another example of dependence on an alphanumeric keyboard. In this case, inputs to the computer are preceded by a one-, two-, or three-letter code which identifies the data being entered and its purpose. Unlike 2F108, this method is not page dependent. For example, an entry of "HD360" during the training exercise will change the aircraft heading to 360 degrees regardless of what page is displayed on the CRT. An entry of "IHD360" will change the aircraft heading on the set of initial conditions being modified. One-letter codes are used for inputs that require brevity for rapid entering. The letter B, followed by the malfunction number, is used to begin a malfunction and R to remove it. As an instructor aid, a page is provided that lists all permissible input codes. Approximately 80 separate codes are used.

Alphanumeric keyboards are a very flexible method of accessing the computer. With either page-dependent or non-page-dependent formats, as in the Device 2F108 or 2F119 respectively, the instructor can be provided a tremendous capacity for performing trainer operating functions and problem control procedures. Most importantly, if methods of instruction change after the trainer is delivered, modifications can be made in displays and instructor procedures with a minimum of expense.

The principal disadvantage in alphanumeric keyboards is the difficulty in typing entries. Formats consisting of several letters and numerals are relatively time-consuming and liable to result in mistakes during typing. This disadvantage is reduced with improved typing skill, but most instructors are not so inclined. It

should be noted that Device 2F108 normally uses both an instructor and an operator, the latter able to be well trained in operating the alphanumeric keyboard.

It is concluded that for the AAHT an alphanumeric keyboard would be a suitable input device, the typing problem notwithstanding, but in this case it is considered that providing it at the instruction station should not be required by the specification. The reason for this opinion is that an acceptable alternative is available, as will be discussed later. Consequently, the alphanumeric keyboard should be viewed as a contractor option, dependent on the formatting approach that he selects. Also pertinent is whether an alphanumeric keyboard or teletypewriter will be available in the computer area.

Function Keyboard. A function keyboard is a grouping of push-button switches that perform various discrete functions such as calling up displays, "freezing" the trainer, overriding a crash, etc. In some cases, separate keyboards are used for homogeneous functions and the panels are labeled with appropriate titles.

In Device 2F108 there are two such panels, one for the instructor and the other for the operator. Push-button switches at the instructor's control panel operate the communications, freeze, crash override, and reset functions. On a panel at the operator's station are switches for the motion system, simulated oxygen system, X-Y recorder, and aircraft position slew functions.

The B-52 digital flight trainer, which Sperry SECOR has delivered to the Air Force, has an even simpler arrangement of instructor controls. There is a single panel containing push-button switches for freeze, reset,

crash override, and five communications channels; two push-button switches to turn on simulated ground service pumps and a hatch warning light; and three slew switches for on-line control of aircraft latitude, longitude, and altitude. Also on the panel are three rotary controls for headset volume, sound effects, and console lighting.

In Device 2F119 there are four panels designated MISSION CONTROL, TRAINER CONTROL, FUNCTION, and AIRCRAFT/COMM CONTROL. Each of the three instructors has different combinations of panels, appropriate to his own area of instructional responsibility. The functions that are switch-operated in Device 2F108 are similarly operated in Device 2F119, except for the X-Y recorder which is replaced in the EA-6B trainer with graphic CRT's. In addition, in Device 2F119 the functions of applying simulated starting air and external power, installing and removing chocks, performing a catapult launch and arrested landing, zeroing the mission clock, selecting and entering initial condition sets, selecting and starting demonstrations, performing replay, and selecting and starting computer-evaluated (performance-measuring) missions are accomplished with switches located on the various panels. Furthermore, all of the basic displays in Device 2F119 are called up by switches on the function panel. If a display contains several pages, the instructor uses a paging key to increment or decrement the pages until he finds the one desired. As a back-up method, each page has a number which can be entered with the alphanumeric keyboard in a manner similar to Device 2F108.

The function panel on Device 2F119 has 32 keys and uses overlays to permit assigning different functions to any key. Up to 16 overlays can be used, hence theoretically 512 separate functions are available. However, it is

undesirable for the instructor to have to change overlays during any single mode of operation, so only four overlays are planned to be used.

It is apparent that function switches solve many of the problems inherent in keyboard-entered formats. Not only are switch operations faster and less susceptible to error, but the fact that each switch can be labeled and located with other related switches assists an instructor in remembering procedures and organizing his activities.

Certainly a function keyboard should be provided on the AAHT. Hardware controls should be provided for operating motion, freeze, crash override, reset, intercommunications, and emergency power-off and for calling up the basic display pages. The overlay system used in Device 2F119 is considered to be somewhat cumbersome and is not recommended.

Numeric/Alphanumeric Matrix. Most alphanumeric keyboards can be purchased with a 12-key matrix of switches containing ten digits and two extra keys that can be programmed to type various symbols or punctuation marks, of which a comma and a period are the most common. Such a matrix enables an instructor to enter numerals somewhat faster than with the top row of keys on the standard alphanumeric keyboard.

A numeric matrix can be purchased separately and, if the formats are designed to be simple, can be used instead of an alphanumeric keyboard, thereby achieving significant economy if a large number of trainers is involved. By programming one of the extra keys to select an upper case function, eleven additional letters or punctuation marks can be added, resulting in an input device similar to that used in airborne navigation computers.

Furthermore, additional keys can be added, producing, in effect, a small alphanumeric keyboard. Device 2B33, the AH-1Q OFT built by Singer Link, has such an input device with 16 keys (without a full range of upper case letters).

A 16-key matrix (or one of similar size) has a number of advantages, besides costs. Because of its compact size, it is especially suitable where space is restricted; and with its limited number of keys, particularly those containing letters, it is easier for an instructor to use than a full-size alphanumeric keyboard.

It is concluded that a matrix with upper case functions, with the number of keys to be determined by the contractor, would be ideal for the AAHT, in view of the number of trainers that is expected to be procured. However, it is believed that whether this type of input device or a standard alphanumeric keyboard is furnished should be discretionary with the offerors; and the trainer specifications should be appropriately broad on the subject.

Thumbwheel. A thumbwheel or digiswitch is sometimes used to input numbers. To handle multi-digit numbers, the required number of switches is arranged in a row, thus the capacity of this method is limited, practically, to three- or four-digit entries. After the switches have been manipulated to select a number, it can be easily inspected to insure accuracy. A separate key or switch must be used to enter the number into the computer.

This method of data entry is useful if it is desired to set a number in the thumbwheel and have it available for reference for a period of time. In Device 2F119, initial conditions sets, demonstrations, and computer-

evaluated missions are selected by this method; each of these three programs has a dedicated thumbwheel and an "enter" switch. Other uses for thumbwheels could include entering tactics mission files, radio facilities sets, airfield data sets, etc. Thumbwheels are not appropriate when speed in entering numbers is important.

Light Pen. A light pen is an input device used to designate symbols or locations on a graphic CRT for certain programming operations. The following are typical uses for a light pen: erasing aircraft tracks to reduce clutter, activating or deactivating emitters, turning off radio facilities, activating or clearing malfunctions from a predetermined list, and initiating threat profiles or programs from a pre-established file.

Some light pens have an optional enhancement feature which causes the symbol being designated to brighten, identifying to the instructor the precise location illuminated. The instructor then completes the operation by a switch action, usually accomplished by pressing the point of the pen against the face of the CRT. Because of its diameter, the end of the light pen tends to obscure the symbol being designated, and the enhancement feature is needed to reduce errors. If an instructor station has multiple CRT's, each must be provided with a light pen to insure that the enhancement feature is uniformly available. A light pen is a very useful tool and simplifies many instructor operations. Using a keyboard to erase aircraft tracks, for example, would be cumbersome and time-consuming.

Some specifications, particularly those published by the Air Force, require that if a contractor proposes to provide a light pen, he must have back-up methods for accomplishing all the functions involved. The basis for

this restriction is believed to be a lack of confidence in the reliability of light pens and/or an appreciation of the ease with which light pens can be pilfered.

Track Ball. A track ball, which positions a cursor over the face of the CRT, performs essentially the same function as a light pen. It normally does not have an enhancement feature; but since the position of the cursor can be easily seen, enhancement of the designated location is not considered to be needed.

Other forms of cursor control are available. A joystick, which is sold by Aydin, accomplishes the identical function as a track ball. Edit keys, which are contained on a matrix that is part of the alphanumeric keyboard provided by Hazeltine, are also used to position a cursor, after which the programming actions can be accomplished.

It is considered that a track ball or equivalent device has advantages over a light pen. The visibility of a cursor is an asset, as well as the fact that a track ball is not easily removed. For these reasons, it is recommended that a track ball be provided for the AAHT.

Paging Keys. Paging keys are used to rapidly increment or decrement CRT pages. Paging keys can be made from spring-loaded toggle switches or similar three-position switches. In Device 2F119, two adjacent keys, the LINE FEED and DEL keys, on the alphanumeric keyboard are used for paging. Depressing one key increments the pages; the other key decrements.

Paging keys are useful when a number of related CRT pages must be called up sequentially. In Device 2F108, for example, the pages containing the checklists for the interior inspection, engine start, post-start, taxi,

pre-takeoff, and takeoff procedure can be called up with a paging key on the alphanumeric keyboard. This operation is considerably faster than entering the various page numbers in the conventional manner.

For the AAHT a paging key would be needed to generate sub-displays after a basic display has been called up via the function keyboard, as recommended previously. Since a small alphanumeric matrix is recommended, the paging key should be a spring-loaded toggle switch or similar control.

Programs

An increasingly important element of any instructional system is the group of programs which are designed to assist the instructor in teaching, evaluating, and critiquing the student. Depending on the number and scope of the programs provided, they make up the instructional capability of the trainer, and make it a teaching tool rather than merely a device to simulate an aircraft. These programs enable the instructor to, for example, control training problems, manipulate malfunctions, play back maneuvers that contain student mistakes, demonstrate the correct way to perform maneuvers, and evaluate student performance. Variously, these programs use CRT displays, hard-copy printouts, and voice and environmental sound recordings. They can be operated automatically or manually. A great variety of such programs is available; those that are potentially applicable to the AAHT are discussed below.

Malfunction Control. Malfunctions are normally controlled through either a function keyboard or an alphanumeric keyboard (or numeric matrix). With a function keyboard, if each switch is used to activate a malfunction, the size of the keyboard becomes inconveniently large when many malfunctions are to be simulated. On the other

hand, the advantage of a function keyboard is that the title of each malfunction can be printed on the face of the switch, making it easy for the instructor to select any malfunction desired.

With an alphanumeric keyboard, each malfunction is activated by entering a discrete number, thus the instructor must usually use an index to determine the number for the malfunction desired. This disadvantage is believed to be more than compensated for by the ability of the alphanumeric keyboard to handle a large number of malfunctions. Device 2F119, for example, has a "library" of over 500 malfunctions, which includes approximately 200 circuit breakers which can be tripped by the instructor. The index requires 11 CRT pages. Clearly, this number of malfunctions cannot be handled by a function keyboard.

Some trainers use a hybrid system consisting of thumbwheels to enter a malfunction number and push-button switches to activate or clear the malfunction. This method appears to have no advantages at all.

Malfunctions are usually programmed for either immediate or future activation. If immediate, the activation occurs when an "enter" switch is depressed or a keyboard carriage return is operated. Future activation is usually programmed by entering a mission clock time into the computer. A number of entries can be made at once, usually at the beginning of a training exercise, and the different activations can be spaced throughout the mission in accordance with the planned events. The scheduled time of activation can be shown in various ways on the CRT displays. Activation of each malfunction occurs automatically when the programmed mission clock time is reached.

This method of programming future malfunctions is not suitable if it is necessary to control the time of activation precisely. For example, if the instructor intends for an engine failure to occur immediately after the start of a missed approach, the student can inadvertently circumvent the planned activation time by normal inability to adhere to exact airspeeds and turn rates during the different maneuvers preceding.

Means can be provided, of course, for the instructor to manually intervene and reschedule the programmed malfunction, but the need for him to do so can be distracting and can affect his other instructional responsibilities. A conditional malfunction program is a better solution.

A conditional malfunction program causes malfunctions to occur when significant criteria have been attained. The criteria can include flight conditions such as airspeed, altitude, and heading; engine conditions such as rpm; and control states such as retraction of the landing gear. Mission clock time can be included when appropriate. Both "and" and "or" logic can be used. When several simultaneous conditions are required to be in effect before activation can occur, the time can be controlled very accurately.

A conditional malfunction program should be able to be constructed by the instructor on line, i.e. either just before or during a training exercise. This requires a CRT page to be assigned for this purpose. The format should enable him to readily enter the conditions and assign logic symbols.

When a conditional malfunction program is required, the specification should define the maximum number of conditions to be used for any malfunction (usually 5),

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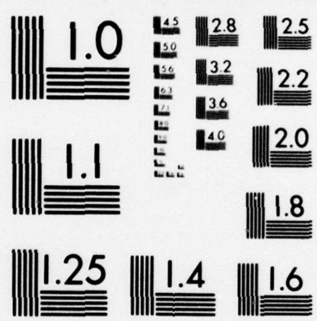
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6.3

the number and type of conditions to be available for use (approximately 10), and the maximum number of malfunctions to be programmed for a training exercise (20 is recommended).

In conclusion, it is recommended for the AAHT that malfunctions be programmable for immediate activation by using the alphanumeric matrix with non-page-dependent formats, and for future activation either by entering a mission clock time or by using a conditional malfunction program.

Procedure Monitoring. An important training objective is to insure that aircrews adhere to established procedures, for both normal and emergency procedures. For this purpose, displays are often provided which contain procedure checklists, derived from authoritative publications such as Flight Manuals. Usually these displays indicate whether the student accomplished all the steps in the procedure and whether they were done in the correct sequence.

In Device 2F108 and 2F119, the steps in each checklist are preceded by a column of sequential numbers. As the student completes each step, a number is displayed in a second column, showing the actual sequence of accomplishment. If the student omits a step or performs one in a wrong sequence, his error can be easily recognized. If the checklist contains a step that cannot be monitored by the computer, a dash is displayed in the second column rather than a number. Steps such as "remove oxygen mask" or "obtain visual check of landing gear" are in this category.

Sometimes it is desirable to determine the time required by a student to complete a procedure. A program to

compute the elapsed time can be developed for this purpose. Such a program usually starts when the malfunction occurs and terminates when the last procedure is accomplished, unless the last procedure cannot be monitored by the computer or consumes an unusual length of time, such as "land at nearest airfield."

It is recommended that procedure monitoring be required for the AAHT and that the two-column approach be specified. Computation of elapsed time is also considered to be a desirable feature for the AAHT.

Dynamic Replay. A dynamic replay program consists of a continuous, automatic recording of the immediately previous events of a training exercise. The purpose is to enable the instructor to interrupt the exercise at any time if he observes the student make a significant mistake, immediately go back to a point preceding the mistake, and then play back the recording of the student's maneuver while pointing out the errors and discussing the correct procedure.

It is considered that dynamic replay can be a powerful instructional tool. With this method, the instructor can point out to the student his errors in an effective way that no other form of critiquing can equal. However, opinion on the value of this technique is not unanimous. At the meeting of the AIAA Working Group on Training Simulation, held at Binghamton, New York, 13-14 April 1977, some representatives from airlines users of simulators stated that they preferred to refly a maneuver rather than spend time during a training exercise in replaying mistakes. On the other hand, a rebuttal from an Air Force representative pointed out that some maneuvers, such as in air-to-air combat, do not have an "approved solution"

and that evaluation can be accomplished only by replay and analysis.

Dynamic replay, if it is provided, usually includes the movement of the flight controls, and the indications of all instruments and indicator lights in the cockpit, as well as all displays used or available at the instructor station. In some versions of dynamic replay, throttle movement is not included, although, in a helicopter trainer, movement of the collective control should always be included, it is believed. The movement of toggle switches and controls such as landing gear and flap levers (not applicable to the AAHT) is almost never replayed, because of the mechanical engineering problems that would be involved. Motion and aural simulation and voice transmissions are usually replayed.

In Sperry SECOR's experience, the period of time available for replay has varied from five minutes, in its A-4 H/N trainers, to 20 minutes, in the EA-6B trainer. The latter period seems excessive, but the recording capability is also used to develop 20-minute demonstrations. Based on observation of the employment of the A-4 H/N trainers, it is concluded that a two-minute replay capability would be sufficient for most needs, but it is believed that users will almost invariably want a five-minute capability.

Controlling the replay can be accomplished either with push-button switches or an alphanumeric keyboard. In the A-4 H/N trainers, five switches are available to enable the instructor to commence the replay at a one-, two-, three-, four-, or five-minute interval preceding. In the EA-6B trainer, replay is commenced by use of a push-button switch but the interval is selected by the instructor entering minutes and seconds via the alpha-

numeric keyboard.

It is recommended that a five-minute dynamic replay capability be provided for the AAHT and that it be controlled with the alphanumeric matrix. Hardware controls as used in the A-4H/N trainers are simpler but require space on the function keyboard that will be at a premium in the AAHT.

<u>Critique Replay</u>. Another form of replay, which is available in Device 2F119 (EA-6B trainer), is a recording of the instructor station displays encompassing an entire training exercise. In Device 2F119 this capability is called "critique replay," and as the title suggests, is to be used for post-exercise crituque purposes. All possible displays are included, whether or not actually generated by the instructor during the exercise. Also included are all student and instructor voice transmissions.

In Device 2F119 the recording is automatic, and the replay is accomplished by a combination of switch and keyboard actions in a manner similar to dynamic replay. By entering the start time with the keyboard, the instructor can select any part of the exercise that he desires to replay. He can do this repeatedly, thus covering only those parts of major interest. In addition, he can operate the replay at X2 and X4 speeds, in addition to normal, thus expediting any portions desired. A limitation exists in the fact that after a portion of an exercise has been replayed once, the instructor cannot replay it again except by returning to the beginning of the entire critique replay program.

To be most useful, a critique replay program should be able to use a display system separate from the instruc-

tor station, such as in a briefing room. With such a capability, thorough critiques can be conducted without interfering with other instructor's and student's use of the trainer.

A critique replay program is not considered to be a requirement for the AAHT, in view of the anticipated availability of a display printout capability, which will provide an equivalent critique aid. Display printout is discussed subsequently.

Demonstrations. Demonstrations consist of recorded maneuvers intended to show the student the correct procedure or technique. In contrast with dynamic replay, which shows the student how he performed the maneuver, demonstrations show how an expert performs it.

Demonstrations can be made either by recording an instructor flying the maneuver or by recording a computer-generated flight which uses ideal parameters (airspeed, heading, etc.). The first method is preferred, because it will contain minor imperfections in flying technique that make the demonstration realistic and credible. The student can attempt to equal or improve on an instructor-generated performance, an impossible goal for a computer-flown maneuver.

During a demonstration the student is in the cockpit observing the instruments and lightly holding the controls. Usually a recorded narrative is available which explains the highlights of the maneuver, bringing out the lessons that the student is expected to learn. Alternatively, the instructor can be required to provide the narrative through the intercom system, but this method, while more economical, can result in uneven instruction.

Demonstrations should include motion and visual simulation (in trainers that have those capabilities), movement

of power and flight controls, simulation of instruments and indicator lights, malfunctions and corrective action, aural simulation, and radio transmissions. The same problems as in dynamic replay will exist regarding reproducing the movement of toggle-switches and landing gear and flap controls, although these difficulties will be reduced in helicopter trainers that do not have many secondary controls. The point can be made that training objectives can be met in many instances by less than complete simulation during demonstrations, but, as usual, user acceptance must be reckoned with.

Demonstrations should also include freeze, replay, and fly-out capabilities. With these features the instructor can stop the demonstration and discuss points of interest in greater detail, replay portions of the demonstration for additional emphasis, and allow the student to complete a maneuver after the demonstration has shown a part of it.

Device 2F119, which possesses a comprehensive demonstration program along the lines discussed above, has special demonstration displays. Required by the specification, these show horizontal and vertical projections of the aircraft flight path, and contain at the bottom of the display a list of the events that occur during the demonstration. All other normal displays are also available for the instructor's use.

Of some value but lesser importance is the capability to conduct part of a demonstration in slow time. This would be useful in a maneuver, such as an instrument takeoff in a helicopter, in which many actions take place in a short time span. Conducting the demonstration at half speed, for example, would allow the narrative, which would be at normal speed, to more easily keep up with the

flight events. An alternative approach would be to freeze the flight every ten seconds, for example, until the narrative covered all the points to be made.

Most users will want to be able to develop their own demonstrations, in addition to those initially delivered by a contractor. Furthermore, there will always be a need to update demonstrations as procedures change. Thus, demonstration programs should be designed to facilitate user preparation, editing, and testing.

During the preparation of a demonstration, one of the most difficult tasks is the coordination of the narrative with the flight events. Controls are needed that will permit the preparer to narrate small portions of the script at a time, repeating those that have errors until the entire script is finally assembled. The controls on Device 2B33 entitled RECORD MANEUVER MARK, FREEZE ON MANEUVER MARK, and EDIT PAUSE are examples of a satisfactory solution to this problem.

It is considered that the AAHT should have a program of demonstrations as described above, except for the special demonstration displays. Recorded narrative; full simulation except for movement of secondary controls; freeze, replay, and fly-out; slow time as well as normal; and controls for user preparation and editing of demonstrations should be required by the specification. The special demonstration displays are considered to be in the "nice-to-have" category, not required because of the availability of other displays. A capability to store on disk approximately 200 minutes of demonstration, to be divided into up to 20 individual demonstration as the user desires, is recommended.

<u>Display Printout</u>. A useful aid for critique purposes is the ability to reproduce significant CRT displays. With

this capability, an instructor can print out, for example, map displays that reveal how a student accomplished a maneuver such as flying a TACAN arc, or alphanumeric displays that contain instrument readings at a critical time in a maneuver such as initiating a missed approach. In some respects, display printout is a duplication of critique replay, if the latter is also available. The advantage of display printout, however, is that it provides a permanent record.

Device 2F119 uses a Versatec printer-plotter to obtain display printouts. This system requires approximately 15 seconds to make a print. Normally, in Device 2F119, the instructor stores all displays of possible interest during a training exercise, then reviews them after the exercise is completed, and finally prints only the ones that he decides to use during the critique. For these functions, the trainer has three momentary-action pushbutton switches labeled CRT STORE, PREVIEW, and PRINT. Another switch, labeled REJECT, enables the instructor to reject displays that he does not want printed. A total of 100 displays can be stored, 50 by the flight instructor and 50 by the tactics (EW) instructor. Since the map displays in Device 2F119 contain a lengthy depiction of the aircraft track, in the form of a dotted line that, under some circumstances, can show over an hour of flight history, the display printout system can be used to record the entire training exercise.

It would be desirable to allow the instructor to print a display immediately if he wishes, without storing a previewing it. This capability would be expensive, however. Two approaches are possible: a software approach that would require substantial memory, or a hardware approach using a Sanders system (the Model 570 Graphic Hard Copy Unit) for reproducing CRT displays, which would

cost approximately $20,000 per system. The Sanders system is not as versatile as the Versatec, hence the latter would still be needed. The cost of immediate printouts would therefore be additive to the 2F119 approach.

The need for immediate printouts should be weighed against these costs. It is considered that the occasions for their use would be infrequent; and, furthermore the instructor would have to accomodate a 30-second interval for every printout, during which he could not print any other display that he might also want. In view of these considerations, it is recommended that for the AAHT only the approach used in Device 2F119 be provided.

Performance Evaluation. Observing and evaluating student performance is one of the most important functions of an instructor, along with initiating and controlling the training exercises. Many aspects of performance evaluation, particularly those that involve obtaining numerical results, are amenable to computer operation. Assistance of this nature from the computer, when available, enables the instructor to devote more attention to those other aspects that require subjective judgment.

A certain amount of controversy exists regarding the dividing line between "objective" measurement that the computer can meke and subjective evaluation that only the instructor can perform. There can be no doubt about the ability of computer programs to measure and record miss distances in weapon delivery, for example; but a question sometimes arises regarding the computer assigning evaluations of "satisfactory" or "unsatisfactory" to such scores, even though the criteria are established by human judgment and are able to be changed by merely modifying the computer program. More controversial is the ability of the

computer to evaluate, in an instrument approach, for example, a student's inability to maintain a prescribed airspeed compared with his failure to remain above the minimum descent altitude. Different parameters can be weighted in the computer program, but there is some reluctance to attempt to assign values to those that are as unlike as the example cited above.

Phases of training that most easily lend themselves to computer evaluation are instrument flight and weapon delivery. Visual flight is also feasible, but only if techniques of evaluating instrument flight are used. Least suitable, for the AAHT, are such phases as target acquisition and identification, response to hostile threats, and communications.

For instrument flight, the technique usually used is to divide a maneuver into segments which contain a number of variables (airspeed, altitude, heading, etc.) that can be evaluated simultaneously. Each variable is assigned a reference value according to the requirements of the maneuver (an altitude of 1000 feet, for example) and a tolerance ($\pm$ 100 feet, for example) which the computer uses to determine whether the student's performance is within standards.

At the end of the training exercise the computer can report overall results in a number of ways. The usual method is to summarize for each parameter the cumulative time out of tolerance and the total number of deviations. In addition, the cumulative time out of tolerance can be divided by the cumulative time of monitoring, resulting in a percentage that can represent a "score" for each parameter.

There are two possible approaches to the design of performance evaluation programs for instrument flight.

These can be entitled "fully automated" and "instructor operated." They are illustrated by Sperry SECOR's EA-6B and A-4H/N trainers, respectively.

In the fully automated program the computer performs all operations, including determining when to start and stop monitoring each parameter, and when to advance from one segment to the next. This method is least demanding on the instructor during an exercise, but has the disadvantage of inflexibility.

Programming an entire training exercise to be monitored via the fully automated approach requires considerable effort, not only in coding the program but also in planning the flight profile, defining the segments, and establishing the reference values and tolerances. Once programmed, an exercise is not readily changed. This inflexibility is recognized in Device 2B33 by the requirement that major segments of the visual and weapon delivery checkrides, which are part of the performance measuring programs, be useable as "automated training exercises."

Fully automated programs are susceptible to anomalies that occur when the student makes mistakes that the program has not anticipated. In this case the computer either advances to the next segment prematurely or fails to advance at all. The result will be that the student is on one segment of a maneuver and the computer is monitoring the parameters of a completely different segment, usually an adjacent one. Consequently, the student will be charged with deviations that are not deserved and not charged with true deviations.

To correct for this problem, Device 2F119 uses two momentary action push-button switches, labeled MANUAL ADVANCE and MANUAL RETARD, to enable the instructor to realign the performance evaluation program with the

student's flight profile.

In the instructor-operated program, the instructor makes the decision when to start and stop monitoring. In fact, in the A-4H/N trainers, the program is designed so that the instructor makes all program entries manually, using the computer only for measuring and recording. Employing a special CRT page, the instructor enters with the alphanumeric keyboard all reference values and tolerances into a column entitled STANDBY. At the proper time in a maneuver, he instructs the computer to start monitoring, and the values then transfer to another column entitled RECORDING. Throughout the exercise, the instructor keeps one segment ahead of the student, entering values for the next segment while the computer is monitoring and measuring those previously entered.

This approach has the advantage of complete flexibility. Normally the instructor will pre-plan all of his entries so that his decisions will only be concerned with starting and stopping the computer monitor function, but he will have the capability to "ad lib" at any time by adding or omitting parameters and modifying tolerances.

On the other hand, this approach has the disadvantage of imposing rather severe demands on the instructor. Only the fact that Sperry SECOR's A-4 series of trainers has a device operator as well as an instructor makes it practical for extensive use. Even with both an instructor and device operator available, it is considered that a maximum of three parameters can be monitored simultaneously during each segment in a normal maneuver.

For the AAHT it is recommended that both fully automated and instructor-operated programs be provided. This approach provides all of the advantages of each - specifically the "capacity" of the fully automated program and

the flexibility of the instructor-operated program. The instructor can use the fully automated method on preplanned missions such as checkrides, and the instructor-operated method for individual maneuvers or short exercises.

Evaluation of weapon delivery usually concentrates on measuring the miss distance rather than monitoring flight parameters. To some degree the two can be combined: dive angle, airspeed, yaw, acceleration, entry altitude, pull-out altitude, etc. can be evaluated during weapon delivery maneuvers in the same way as during instrument flight, if the criteria for satisfactory performance can be determined. However, the result of improper procedures will usually be an unsatisfactory miss distance, hence it seems to be adequate to evaluate only the latter.

For the AAHT, the normal weapon delivery maneuver will consist of a stable hover behind or emerging from some type of concealment, and the parameters that could logically be evaluated are limited. The time to acquire the target and launch a weapon could be one. Otherwise, it is concluded that only accuracy measurements need be computed, i.e., miss distance and relative location of impact.

On Device 2B33 the weapon delivery display contains read-outs for altitude, airspeed, heading, and other flight parameters. These will be useful if display printouts are made of this page during weapon delivery, and a similar approach should be followed for the AAHT.

<u>Displays</u>

Displays serve a number of purposes in a trainer's instructional system. First, they are the means by which the instructor observes the altitude, location, and performance of the simulated aircraft, and monitors the

progress of the student through training exercises or problems. Second, displays can contain reference data, such as an index of pages or lists of malfunctions or emergency procedures. This type of information can be contained elsewhere, such as in instructor handbooks, but having it available on the CRT is more convenient for the instructor. Finally, displays are often part of the process by which the instructor accesses the computer. Device 2F108, with its relative, few hardware controls and its page-dependent CRT formats, is an example of this function.

Considering the above purposes, one can define the use of displays as being either informational or instructive. Combinations of these uses are possible on any single display page, although in Device 2F108 this practice is minimized and purely informational displays are called "monitor" pages.

Another way of classifying displays is by format. From this viewpoint, displays can be categorized as either graphic or tabular. Most graphic displays are map-like and are generated by a program that draws vectors and curves and records the aircraft position and track. Another form of graphic display depicts aircraft instruments, and is usually called psuedo-instrument display. Tabular displays contain tables or lists of alphanumeric data. Combinations of these formats are frequently used.

Repeater instruments are a form of display. They have the advantage of being easy for the instructor to interpret, and the disadvantages, compared with psuedo-instrument displays, of greater cost and less reliability. Repeater instruments are usually not provided when the instructor station is located in or beside the cockpit and the instructor can observe the aircraft instruments directly.

__Graphic Displays__. Map displays, the most common form of graphic displays, can be classified into four types: cross-country, combat situation, terminal area, and GCA/ILS. Some combinations are possible, but the general practice is to keep them separate.

Cross-country displays usually depict the radio navigation aids (TACAN's, VOR's, and non-directional beacons) located in a commonly-used training area such as the vicinity of Fort Rucker, Alabama. Sometimes symbols representing airfields, obstructions, and elevations, and lines to indicate airways are included. Inasmuch as instrument navigation will be a capability of the Advanced Attack Helicopter, the AAHT should have a cross-country display for such training.

Since AAHT's will be procured for field use, it is recommended that the instrument training gaming area and cross-country displays be designed to represent the area in which the trainer site is located. For example, Fort Hood-based trainers should have a cross-country display oriented around that area of Texas; and the Fort Knox-based trainers' display should depict Kentucky and surrounding states.

Combat situation displays, often provided for trainers with an electronic warfare mission, usually depict hypothetical combat areas not identified with a specific locality, although geographic accuracy would be easily possible and might enhance training. Normally, the instructor is able to program threats at various locations and control their responses to ownship actions.

Combat situation displays are not expected to be provided when the trainer has a visual system, since the instructor can see the geographic features and threat locations directly. However, it is considered that a combat situation display consisting of a map of the visual

system area would assist the instructor in monitoring the progress of training exercises. Such a display should have surface topographical and cultural features defined with contour lines and appropriate symbols, should depict the aircraft track with a continuous or interrupted line, and should show the location of targets and threats with symbols and descriptive legends. The display combat situation could be used by the instructor to program threats on the visual display and otherwise control the problem situation.

Terminal area displays, using a scale considerably larger than for cross-country displays, depict the area surrounding an airfield, or group of airfields, and contain symbols for the airfields and the radio aids associated with the various approaches. Data on airfield elevation and radio frequencies available are usually included. In Device 2F119 (EA-6B Trainer) there are approximately 120 terminal display pages depicting the principal Navy, Marine Corps, and Air Force airfields in the United States.

A special category of terminal area displays is approach departure displays. These displays depict published instrument approach and departure patterns on which the track of the aircraft is superimposed as the student performs the prescribed procedures. The displays contain symbols for radio aids, marker beacons, obstructions, ILS localizer courses, and holding patterns, and show all appropriate course lines with magnetic headings. These displays are very useful to the instructor in monitoring that phase of instrument training.

Sperry SECOR's B-52 trainers display all published approach and departure patterns for Castle, March, and Beale Air Force Bases, which are contained in the gaming area for those trainers. Each pattern is depicted on a

separate CRT page; there are 19 such pages in total. For larger gaming areas involving a greater number of bases, some selectivity should be exercised. For Device 2F119 Sperry SECOR has proposed to provide 15 displays for bases to be determined, with storage for 35 additional which the users, at NAS Whidbey Island, will program themselves.

It is considered that approach/departure displays should be designed to meet the instrument training needs of the local user, in the same manner as recommended in cross-country displays.

GCA/ILS displays normally contain a vertical projection of the final approach course and a horizontal projection of the glide slope. Aircraft symbols and tracks are shown on both projections. Usually the scale of the glide slope angle is exaggerated, i.e., a 3-degree glide slope is shown as approximately 15 degrees. The angle is normally fixed, regardless of whether a different glide slope, such as 2.5 degrees, is required. If the aircraft has ILS, both ILS and GCA approaches can be monitored with the same display. In Device 2F108, 2F119, and Sperry SECOR's B-52 trainers, the GCA displays contain a text providing standard GCA instructions so that the instructor need only read them verbatim to the student. These instructions change every few seconds, as required by the student's flight path.

It is recommended that the AAHT be provided a GCA/ILS display similar to that described above. If the aircraft has ILS, the instructor will be able to observe the student's instrument during ILS approaches or can use the GCA/ILS display.

It is possible to provide an automatic voice recording

of all GCA instructions, thus relieving the instructor cf having to read those on the CRT display. Such a system either would require a separate recorder, an expensive approach; or could use the recorder capability dedicated to dynamic replay, which would prevent it being used for the latter function. In view of these undesirable aspects, such a capability is not recommended.

<u>Tabular Displays</u>. Tabular displays comprise those displays containing only alphanumeric data rather than graphic depictions. They can serve any of the purposes outlined previously - student monitoring, information storage or computer interaction. The programs recommended for the AAHT will require certain tabular displays; other displays are dictated by the normal requirements of trainer operation. The following tabular displays are considered to be necessary or highly desirable:

Initial Conditions. Defines the flight and environmental conditions for the commencement of a training exercise. Ten sets (each set to be displayed on a CRT page) are recommended.

Malfunctions. Lists all programmable malfunctions. Assigns each number to be used in the input format.

Conditional Malfunction Programming. Provides a format for the instructor to use in instructing a conditional malfunction program, and in modifying one that has been constructed earlier.

Procedure Monitoring. Lists the sequential steps for each normal and emergency procedure. The appropriate procedure can be automatically displayed when a malfunction occurs, a feature that is recommended for the AAHT (a manual override to inhibit the automatic feature is also recommended).

Procedure Index. Lists all procedure monitoring displays. Used by the instructor to manually generate a display.

Performance Evaluation (Automated). Displays the current segment for an automated performance evaluation program and shows the parameters being monitored with their reference values and tolerances. The previous and next segments can be included. Also, any out-of-tolerance values resulting from student errors can be reported via this display.

Performance Evaluation (Instructor-Operated). Provides a format to be used with an instructor-operated performance evaluation program. Permits the instructor to manually enter and store reference values and tolerances and to start and stop recording at will. Can display out-of-tolerance values.

Weapon Delivery. Provides results of weapon delivery, i.e., rounds fired and rockets/missiles launched, hits, miss distances and impact points or areas. Can include existing station loading positions of cockpit select switches, and aircraft flight data that would assist instructor in evaluating weapon delivery.

In addition to the displays listed above, a page is needed for programming in-flight changes in aircraft status and configuration and environmental conditions. Parameters such as aircraft latitude/longitude, altitude, heading, airspeed, fuel quantity, internal stores, wind direction and velocity, barometric pressure, etc. would be listed on the page and would be able to be modified at any time by the instructor making keyboard entries as described previously for Device 2F108. Visual system functions could also be controlled by the same method.

This approach was used by Sperry SECOR in its B-52 trainers. A CRT display entitled the MONITOR/CONTROL page contains approximately 40 informational and 25 programmable items. It is the only page used for interaction with the computer; all other pages are for monitor functions.

With respect to the AAHT, it is considered that the method used to perform on-line programming should be discretionary with offerors and that the specification should not require a monitor/control page. Sperry SECOR, however, prefers this approach.

Common Displays. Many displays contain an area in which flight status and other information of frequent interest to the instructor is continually shown. In Sperry-SECOR's B-52 trainers this is called the Reserved Area; in Device 2F119 it is called the Common Area. In both trainers it is only contained on the graphic displays. In Device 2F108, this area is called the Status and Indications Display, and is contained on most of the tabular displays (there are no graphic displays). A similar area is contained on displays of Device 2B31 and 2B33.

It is recommended that the specification for the AAHT stipulate that a common area be provided on all graphic displays and that it contain the following information:

Flight Status. Indicated airspeed, baro altitude, magnetic heading, vertical speed, rotor rpm, torque, fuel remaining, wind direction and velocity. This data should be up-dated every second.

Malfunction Status. Number and abbreviated title of all existing (activated) malfunctions.

Communications Status. Frequencies of all tuned-in

and operating equipment. SIF code selected if the AAH is so equipped.

The common area displays in Device 2B31 and 2B33 contain a plot of altitude and airspeed for the preceding 12-minute period. It is considered that this feature is of marginal value and is not recommended to be specified in the AAHT.

Summary

The foregoing discussion of instructional system controls, programs, and displays is summarized in Tables 25, 26 and 27.

Instructor Station Configuration

Once the controls, programs and displays are specified, the configuration of the instructor station remains to be defined. The first requirement is to specify the number and size of the CRT's. It is considered that the same philosophy should apply in this case as to instructor station controls, i.e., the specification should be as explicit as possible, to insure that the user receives a desired level of performance.

It is believed that the functions contemplated for the AAHT and the displays recommended will require at least two 21-inch CRT's at the instructor station. During instrument flight training, the instructor will usually use one of the map displays and the monitor/control page or perhaps the performance evaluation display. During training in emergency procedures, the malfunction display and procedures monitoring display will be used. During training using the visual system, the instructor will probably want the combat situation display and the monitor/control display. The instructor will be able to monitor flight status by keeping in view a graphic display

Table 25. Instruction System Controls

EQUIPMENT	APPLICATION TO AAHT	TO BE SPECIFIED
Alphanumeric Keyboard	Possible input device	No
Function Keyboard	Contains hardware controls	Yes
Numeric Matrix	Additional input device	No
Alphanumeric Matrix	Substitute for alphanumeric keyboard	No
Thumbwheel	Possible input device	No
Light Pen	Possible input device	No
Track Ball	Substitute for light pen	Yes
Paging Key	Rapid access of display pages	Yes

Table 26. Instructional System Programs

PROGRAM	APPLICATION TO AAHT	TO BE SPECIFIED
Immediate Malfunctions	Initiates malfunctions on instructor demand.	Yes
Future Malfunctions	Uses mission clock to program malfunctions for future occurrence.	Yes
Conditional Malfunction	Uses algorithms to cause automatic initiation of malfunctions. Reduces demands on instructor.	Yes
Procedure Monitoring	Evaluates student adherence to published emergency and normal procedures.	Yes
Dynamic Replay	Replays trainer activity and instructor station displays for immediate use.	Yes
Critique Replay	Selectively replays instructor station displays during entire exercise. For post-exercise critiques.	No
Demonstrations	Replays correctly-performed maneuvers for student to observe.	Yes
Display Printout	Prints CRT displays selected by instructor.	Yes
Performance Evaluation		
Instrument Flight	Using predetermined standards, evaluates student performance along segments of a pre-planned instrument flight profile.	Yes
Visual Flight	Evaluates student performance along segments of a pre-planned visual flight profile.	No
Target Acquisition	Not feasible.	No

Table 26 (Cont.)

PROGRAM	APPLICATION TO AAHT	TO BE SPECIFIED
Weapon Delivery	Determines impact points and miss distances	Yes
Response to Hostile Threats	Not feasible	No
Communications	Not feasible.	No

Table 27. Instructional System Displays

DISPLAY	APPLICATION TO AAHT	TO BE SPECIFIED
Cross-Country	Depicts instrument training area	Yes
Terminal Area	Depicts area around airfields	Yes
GCA/ILS	Depicts final approach course and glide slope	Yes
Combat Situation	Depicts combat training area	Yes
Approach/Departure	Depicts Standard Instrument Departures (SIDs) and published approaches	Yes
Initial Conditions	Defines initial flight and environmental conditions	Yes
Malfunctions	Lists all programmable malfunctions	Yes
Conditional Malfunction Programming	Provide format for conditional malfunction programming.	Yes
Procedure Monitoring	Lists steps in each normal and emergency procedure	Yes
Procedure Index	Lists all procedure monitoring displays	Yes

Table 27 (Cont.)

DISPLAY	APPLICATION TO AAHT	TO BE SPECIFIED
Performance Evaluation (Automated)	Displays segments of automated performance evaluation program	Yes
Performance Evaluation (Instructor Operated)	Provides format for instructor - operated performance evaluation program	Yes
Weapon Delivery	Provides weapon delivery results	Yes
Monitor/Control	Provides a vehicle for on-line parameter changes	No
Common Area	Provides flight status info on all displays	Yes

which will always have a common area display. During training in emergency procedures it will be necessary to alternate between one of the tabular displays and a graphic display such as the cross-country page in order to keep a common area in view. Nevertheless, it is considered that this and other similar situations will be acceptable to the instructor and will not necessitate providing a third 21-inch CRT.

In order to monitor the pilot and copilot/gunner visionic displays, the instructor will need two dedicated CRT's. Five-inch CRT's are recommended. As each crewman selects a TADS, PNVS, or IHADSS display, the CGI image that he sees on his cockpit displays will be reproduced on the instructor station CRT's.

In addition, five 7-inch CRT's will be needed to enable the instructor to monitor the visual scene. These should be arranged horizontally, probably along the top of the instructor's console.

In view of the fact that the common area can contain readouts of all flight and engine instruments, a repeater instrument panel or a pseudo-instrument display is not recommended. However, a repeater ADI should be installed.

The specification should require that MIL-STD-1472A be adhered to in the design of the instructor station, with particular reference to a 15-degree downward line of sight. This requirement is intended to provide for instructor comfort, and results in the 21-inch CRT's being mounted with the larger dimension horizontal.

Some ingenuity will be required in designing displays and arranging the controls and input devices. Unfortunately, in the past, too little attention has been to the needs of the instructor. Both efficiency and comfort can be achieved if the effort is made.

APPENDIX A

HELICOPTER FLIGHT SIMULATION

The block diagram of Figure A-1-1 shows the computation flow and functional dependencies among elements of a helicopter aerodynamic math model. Table A-1 defines the symbols for the variables used in the figure and in the discussion of aerodynamic equation derivation that follows.

Equations of Motion

The equations for computing linear accelerations are classical ones:

$$\dot{U}_G = \frac{X_a}{m_i} - g \sin \Theta + V_G r - W_G q_1$$

$$\dot{V}_G = \frac{Y_a}{m_i} + g \cos \Theta \sin \phi - U_G r + W_G P$$

$$\dot{W}_G = \frac{Z_a}{m_i} + g \cos \Theta \cos \phi + U_G q_1 - V_G P$$

where

$$X_a = X_R + X_F + X_{LG} + \Delta X$$

$$Y_a = Y_R + Y_F + Y_{LG} + \Delta Y + Y_{TR}$$

$$Z_a = Z_R + Z_F + Z_{LG} + \Delta Z$$

The increments ΔX, ΔY, and ΔZ represent miscellaneous forces, such as those arising from turbulence.

Angular accelerations are computed by the equations:

$$\dot{p} = \frac{1}{I_{xx}} \left[L_a + (I_{yy} - I_{zz})\, q_1 r + J_{xz}\,(p q_1 + \dot{r}) \right]$$

$$\dot{q}_1 = \frac{1}{I_{yy}} \left[M_a + (I_{zz} - I_{xx})\, pr + J_{xz}\,(r^2 - p^2) \right]$$

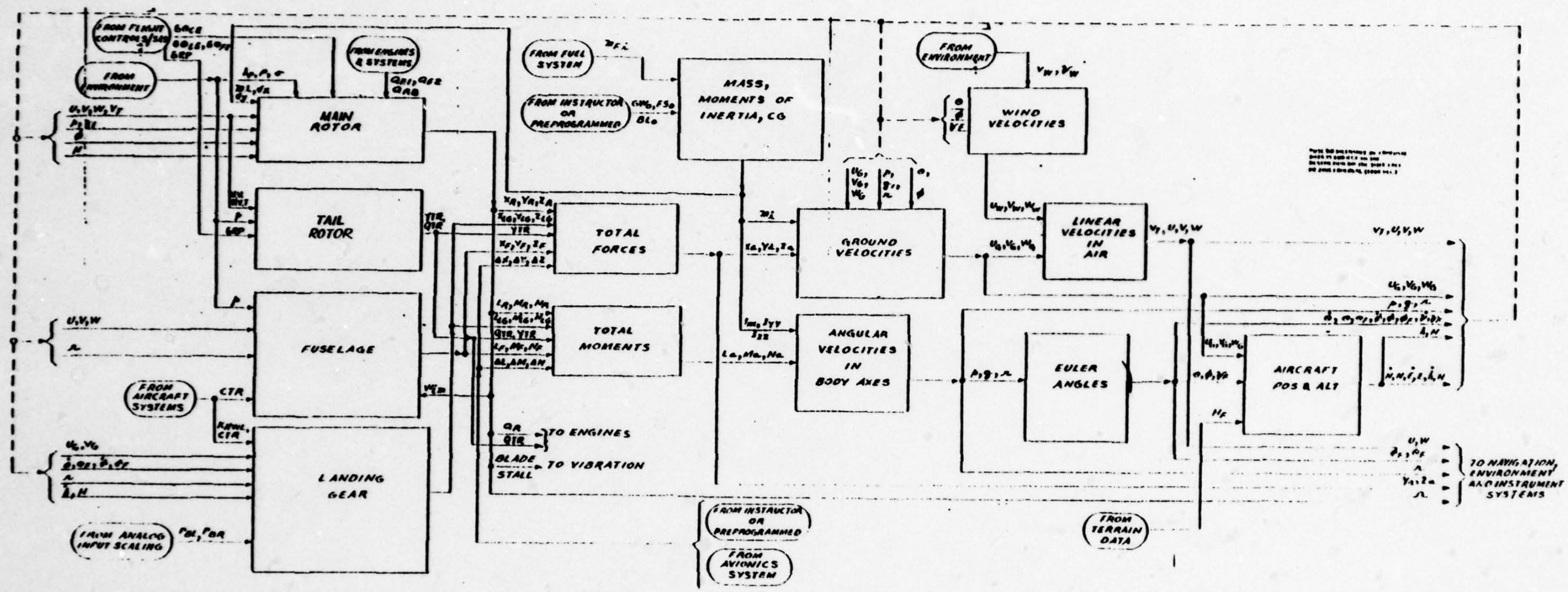


Figure A1-1. Aerodynamic Math Model Block Diagram

TABLE A-1

SYMBOLOGY

Symbol	Description
a_o	Coning angle of rotor
a_1	Longitudinal flap angle of tip-path plane with respect to no-feathering plane
a_{1s}	Longitudinal flap angle of tip-path plane with plane normal to shaft
A_{1s}	Rotor Lateral control angle
B	Blade tip loss factor
b_1	Lateral flap angle of tip-path plane with respect to control plane
b_{1s}	Lateral flap angle of tip-path plane with plane normal to shaft
B_{1s}	Rotor longitudinal control angle
BL_o	Butt line of CG
c	Effective chord of blade
CD_{AV}	Average section drag coefficient
C_L	Section lift coefficient
CTR	Index of landing gear position
dx	Longitudinal displacement of CG from references, + forward
dy	Lateral displacement of CG from reference, + forward
$\dot{E}$, E	Eastward velocity, east position of aircraft
$F_{LW}(F_{RW},F_{NW})$	Force on landing gear left (right, nose) wheel
FH_{LG}	Landing gear horizontal force, inertial system

TABLE A-1 (cont'd)

SYMBOLOGY

Symbol	Description
FS_o	Fuselage station of CG
FS_{REF}	Fuselage station of reference CG
FV_{LG}	Landing gear vertical force, inertial system
GW	Gross weight
$\dot{h}$	Rate of climb
hp	Pressure altitude
H	Height of aircraft above field
H_F	Height of field
H_R	Longitudinal in-plane force of rotor
i_{s1}	Longitudinal tilt of rotor shaft
$I_{xx}(I_{yy},I_{zz})$	Moment of inertia about X(Y,Z) axis
J_{xz}	Product of inertia
L_a	Total rolling moment
L_F	Fuselage rolling moment
L_{LG}	Landing gear rolling moment
L_R	Rotor rolling moment
L_{RH}	Rotor hub rolling moment
L_{STALL}	Rolling moment due to blade stall

TABLE A-1 (cont'd)

SYMBOLOGY

Symbol	Description
M_{f_i}	Mass of fuel in tank i
m_{STO_i}	Mass of stores at station i
M_a	Total pitching moment
M_F	Fuselage pitching moment
M_{LG}	Landing gear pitching moment
M_R	Rotor pitching moment
M_{RH}	Rotor hub pitching moment
M_{STALL}	Pitching moment due to blade stall
$\dot{N}$, N	Northward velocity, north position of aircraft
N_a	Total turning moment
N_F	Fuselage turning moment
N_{LG}	Landing gear turning moment
N_R	Rotor turning moment
$\dot{p}$, p	Rolling acceleration, rate
$P_{BL}(P_{BR})$	Pressure in left (right) brake line
P_{EO}	Engine oil pressure
P_{SL}	Barometric pressure at sea level
$\dot{q}_1$, q_1	Pitching acceleration, rate

TABLE A-1 (cont'd)

SYMBOLOGY

Symbol	Description
q_F	Dynamic pressure on fuselage
$Q_{E1}(Q_{E2})$	Engine 1 (engine 2) torque
Q_R	Rotor torque
Q_{TR}	Tail rotor torque
$\dot{r}$, r	Turning acceleration, rate
R	Radius of rotor
SHP	Shaft horsepower
S_R	Lateral in-plane force of rotor
STALL	Rotor in stall (logical variable)
S_X	Horizontal displacement of rotor hub from Z body axis (+ fwd)
T	Rotor thrust
t_o	Outside air temperature
T_o	Air temperature at sea level
U	Longitudinal air velocity
U_G	Longitudinal ground velocity
U_W	Wind velocity component along X body axis
v_w	Wind velocity
V	Lateral air velocity
V_{DD}	Drag-divergence velocity
V_G	Lateral ground velocity

TABLE A-1 (cont'd)

SYMBOLOGY

Symbol	Description
V_T	True airspeed
V_W	Wind velocity component along Y body axis
V_{xy}	Velocity in X-Y plane
W	Vertical air velocity
W"	Inflow velocity normal to no-feathering plane
W_f	Fuel flow
W_G	Vertical ground velocity
W_{im}	Average induced velocity of rotor
W_W	Wind velocity component along Z body axis
X_a	Total longitudinal force
X_F	Fuselage longitudinal force
X_{LG}	Landing gear longitudinal force
X_R	Rotor longitudinal force
Y_a	Total lateral force
Y_F	Fuselage lateral force
Y_{LG}	Landing gear lateral force
Y_R	Rotor lateral force
Y_{TR}	Tail rotor side force
Z_a	Total vertical force

TABLE A-1 (cont'd)

SYMBOLOGY

Symbol	Description
Z_F	Fuselage vertical force
Z_{LG}	Landing gear vertical force
Z_R	Rotor vertical force
$\delta\theta_{CE}$	Effective collective pitch stick deflection
$\delta\theta_{FE}$	Effective longitudinal cyclic pitch stick deflection
$\delta\theta_{LE}$	Effective lateral cyclic pitch stick deflection
δ_{RP_E}	Effective directional control pedal deflection
ΔL, ΔM, ΔN, ΔX, ΔY, ΔZ	Increments in forces and moments due to miscellaneous aerodynamic effects
$\dot{\theta}, \theta$	Pitch angular velocity, angle
θ_F	Fuselage pitch angle
θ_o	Mean pitch of rotor blade at root
ρ	Air density
σ	Air density ratio
$\dot{\phi}, \phi$	Roll angular velocity, angle

TABLE A-1 (cont'd)

SYMBOLODY

Symbol	Description
ϕ_F	Fuselage roll angle
Ψ_F	Fuselage heading angle
Ψ_w	Wind heading
Ω	Rotor rotational velocity

$$\dot{r} = \frac{1}{I_{zz}} \left[N_a + (I_{xx} - I_{yy})\, pq_1 + J_{xz}\, (\dot{p} - q_1 r) \right]$$

where

$$L_a = L_R + L_{TR} + L_F + L_{LG} + \Delta L$$

$$M_a = M_R + M_{TR} + M_F + M_{LG} + \Delta M$$

$$N_a = N_R + N_{TR} + N_F + N_{LG} + \Delta N$$

The increments in the moment summations have the same significance as in the force equations.

Euler Angles

The Euler angles used in coordinate conversion can be computed by the equations:

$$\dot{\phi} = p + \dot{\Psi} \sin \Theta$$

$$\phi = \int \dot{\phi} \; dt$$

$$\dot{\Theta} = q_1 \cos \phi - r \sin \phi$$

Rotor Aerodynamics

The Specific Response Approach (SRA) is characterized by a set of equations which describe helicopter rotor performance and reaction by directly computing the composite rotor forces and moments without necessitating the prior development of intermediate microparameters. In this computational system, many of the variables which are pertinent to the blade element approach, for example, simply do not exist. The tangential velocity at a given point on the blade is a necessary variable in the blade element approach and varies considerably during forward flight at different points in the rotor disc. The SRA uses what could be considered an average tangential velocity for the rotor disc ($\frac{1}{2} R\Omega$ where R is the rotor radius and Ω the rotor rotational velocity). Other quantities which the SRA does not need to compute are perpendicular velocity $Up_{\psi -y}$; local inflow velocity $W_{i\ \psi\ -y}$; local attack angle $\alpha_{\psi -y}$;

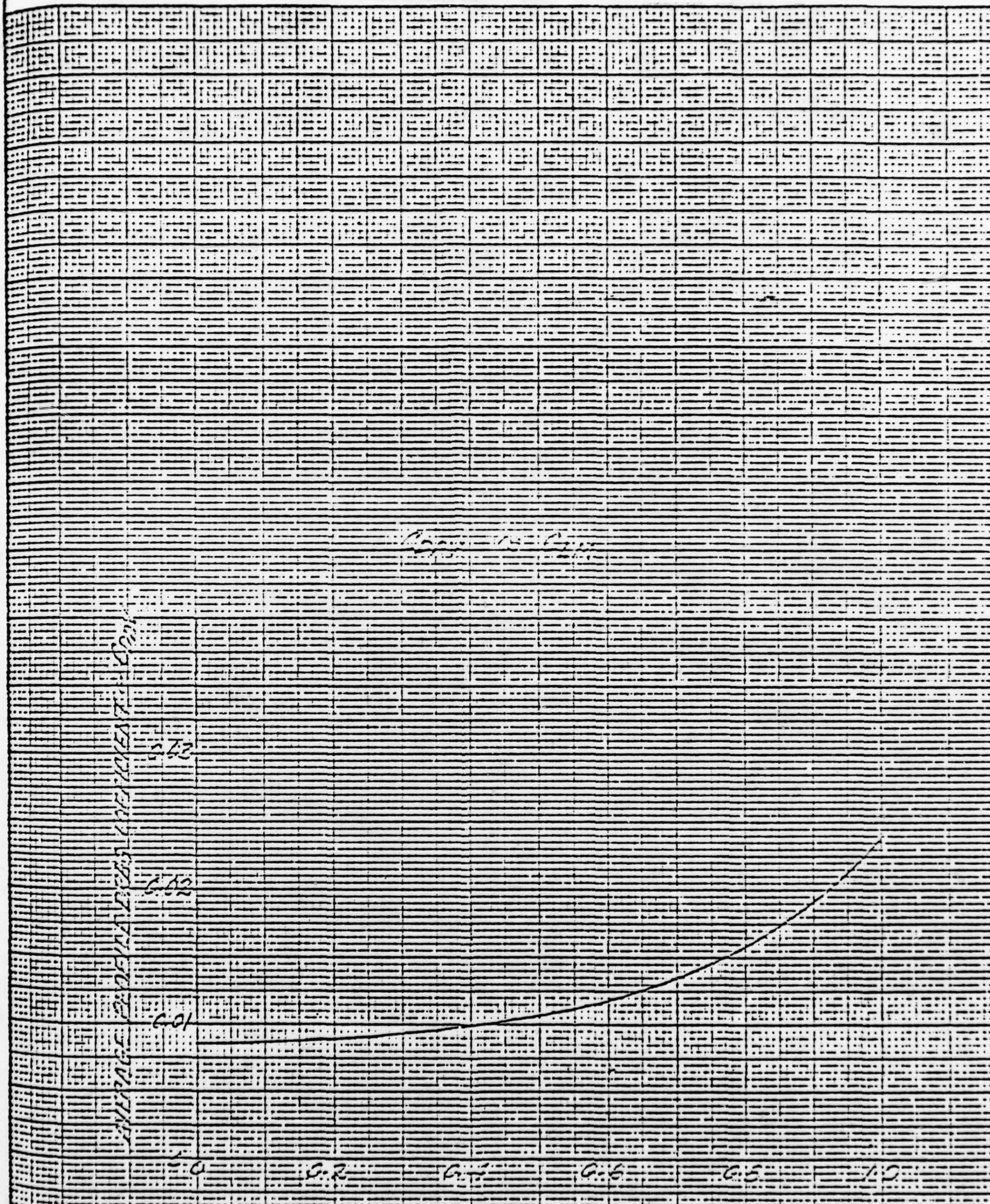
coefficient of drag $C_{D\,\psi\text{-}y}$; and coefficient of lift $C_{L\,\psi\text{-}y}$.

The SRA does not rely on local inflow computation but instead uses the mean inflow velocity, which is a direct measure of thrust. This can be easily and accurately computed. SECOR generated Revision 3 dated July 1972 to the Dynamics Report for Device 2B18 Basic Helicopter Instrument Trainer (NAVTRADEVCEN 1848-7) which showed the derivation and application of the SRA equation set for the TH-1L helicopter. This showed the generation of the mean profile drag coefficient, C_{DAV} as a function of the mean lift coefficient C_{LM}, as well as the analytical expression for computing C_{LM} for use in computing main rotor torque. Figure A1-2 shows the relationship between C_{DAV} and C_{LM} as presented in the revised Dynamics Report. Figure A1-3 is the tip speed (μ) correction factor which is applied to C_{LM}. The resulting simulation performance of the revised equation set installed in Device 2B18 was tested and found to yield in-tolerance static and dynamic results throughout the flight envelope.

The simplifying assumptions underlying the rotor simulation are that the induced velocity is uniform over the rotor disk; the slope of the curve of local lift coefficient of the blade versus local angle of attack is constant; and for a given flight condition the local drag coefficient may be replaced by an average coefficient identical for all blade sections. With these assumptions, the expressions for incremental forces are integrable along the blade and around the disk; that is, equations of the form

$$T = \frac{1}{2\pi} \int_0^{2\pi} \int_e^{BR} dt$$

have analytical solutions. The simulation equations for thrust, flap angles, induced and profile torque losses, and in-plane forces can be derived from such equations. The effects of these



Revision

Figure A1-2

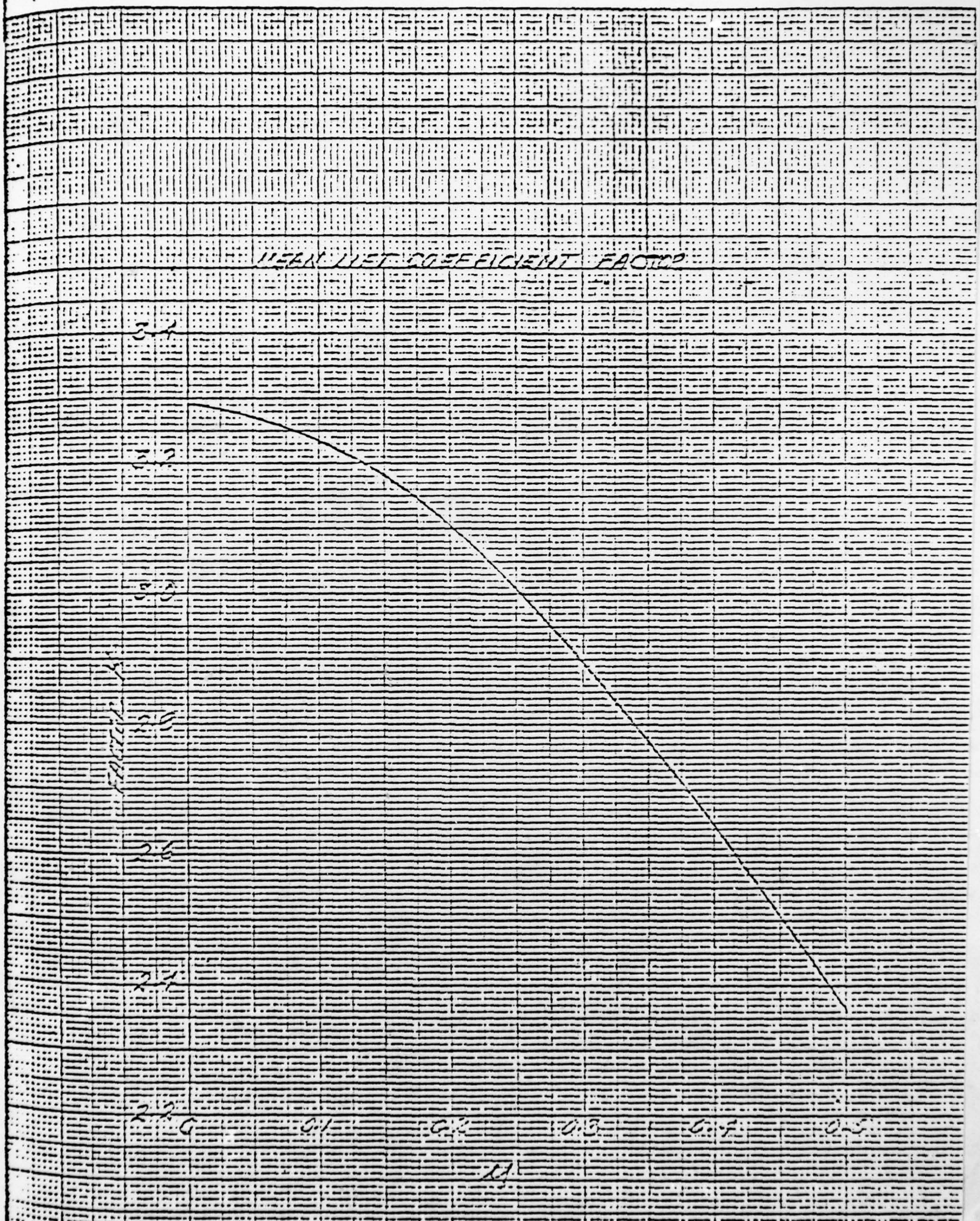


Figure A1-3

simplifying assumptions are discussed in the derivation of equations.

Ground effects are introduced into the thrust equation as a function of slipstream length, which is determined from forward velocity, induced velocity, and height of the aircraft above the field.

First approximations to rotor forces along the body axes are obtained by resolving thrust through the flap angles. If the resultant of all aerodynamic forces of the rotor were perpendicular to the tip-path plane, these approximations would be very close. The rotor does, however, generate in-plane forces; that is, forces parallel to the tip-path plane. The longitudinal component of in-plane forces is generally small compared with the longitudinal component of thrust, and may in some instances be neglected in the interest of computation economy. The lateral component of in-plane forces, on the other hand, is proportionately large and should be included.

Rotor moments about the body axes are the products of the aerodynamic forces along the axes and the arm through which they act on the aircraft reference center of gravity, plus moments imparted to the hub by the projection of the inertial force of flapping parallel to the shaft times the distance from the flap hinge to the center of rotation.

The derivation of the equations for rotor forces and moments begins with the expressions for the forces acting on a blade element and the resulting moments about the flapping hinge. Elementary thrust (dT), centrifugal force (dCF), inertial force due to flapping (dF), and Coriolis force (dC) are represented in Figure A1-4. A fifth force weight, is not shown. Moments about the flapping hinge corresponding to these forces are expressed as follows:

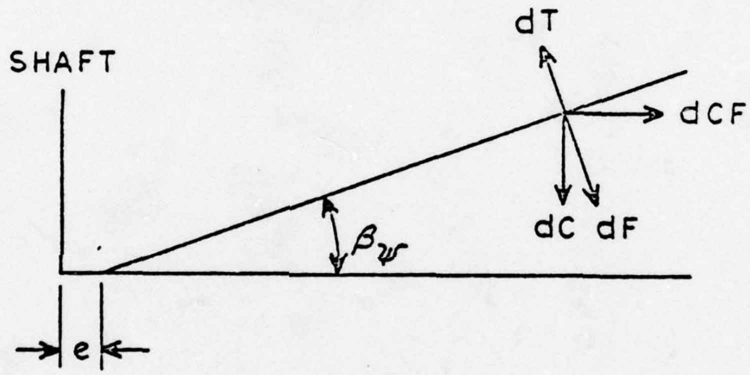


FIG. A1-4 FORCES ON ROTOR BLADE ELEMENT

Moment of flapping force $\quad -\int_e^R \ddot{\beta}_\Psi m r^2 \, dr$

Moment of centrifugal force $\quad -\int_0^R \beta_\Psi \Omega^2 m r^2 \, dr$

Moment of Coriolis forces $\quad -\int_0^R 2\Omega(q_1 \sin\Psi - p\cos\Psi)$

$mr^2 \, dr$

Thrust moment $\quad +\int_e^{BR} r \, dT$

Static Moment $\quad -\int_0^R mgr \, dr$

Let $\int_e^R mr^2 \, dr = \int_0^R mr^2 \, dr = I_B$ and $\int_0^R mr = M_B r_B$.

Then

$$- I_B \ddot{\beta}_\Psi - I_B \Omega^2 \beta_\Psi - I_B 2\Omega(q_1 \sin\Psi - p\cos\Psi)$$

$$- M_B r_B g + \int_e^{BR} r \, dT = 0$$

The particular solution to this equation is a Fourier series

$$\beta_\Psi = a_o - \sum_{n=1}^{\infty} (a_n \cos n\Psi + b_n \sin n\Psi)$$

Practical experience has demonstrated that the flap angle can be represented with acceptable accuracy by the first three terms of this series:

$$\beta_\Psi = a_o - a_1 \cos\Psi - b_1 \sin\Psi$$

The moment equation can be simplified by expressing differentiation with respect to time as differentiation with respect to the angle Ψ (which equals Ωt) and then substituting the truncated Fourier series for $\beta\Psi$.

Since

$$\ddot{\beta} = \Omega^2 (a_1 \cos\Psi + b_1 \sin\Psi)$$

the moment equation takes the form

$$-I_B \Omega^2 a_o - 2I_B (q_1 \sin\Psi - p \cos\Psi) - M_B r_B g + \int_e^{BR} r\, dT = 0$$

Solution of this equation for the Fourier coefficients now depends on deriving an integrable expression for elementary thrust involving these coefficients. Such an expression will first be developed for a rotor with an untwisted blade and no cyclic variation in pitch and then modified for a rotor system which has both twist and cyclic variation in pitch.

By classic aerodynamic theory, elemental thrust $dT = q\, C_L dS$, where q is the dynamic pressure, C_L the lift coefficient of the element, and dS the area of the element. Set $q = \frac{1}{2}\rho U_E^2$ and set $dS = c\, dr$, where U_E is the velocity of air acting on the blade element, c the blade chord, and r the distance of the element from the center of rotation. Then

$$dT = \tfrac{1}{2} \rho\, c\, C_L\, U_E^{\,2}\, dr$$

The velocity U_E of the air acting on the blade element can be resolved into two components U_T and U_p lying along coordinate axes in a plane perpendicular to the blade axis, as shown in Figure A1-5.

$$U_T = \Omega r + U \sin\Psi + V \cos\Psi$$

$$U_P = W' - (r-e)\dot{\beta}\Psi - \beta\Psi (U \cos\Psi - V \sin\Psi)$$
$$+ r (q_1 \cos\Psi + p \sin\Psi)$$

where $W' = W - W_i$

Since W_i cannot be defined with an acceptable degree of accuracy, we assume that it is uniform over the disk, i.e., $W_i = W_{im}$.

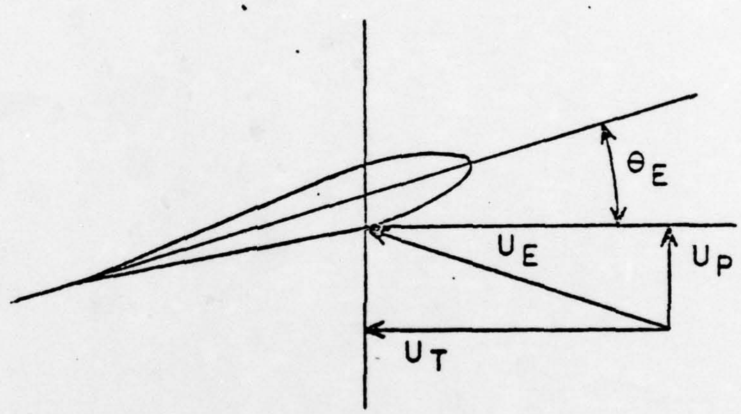


FIG. A.1-5 BLADE ELEMENT VELOCITIES

Over most of the velocity regime C_L is a linear function of blade element angle of attack α_E; that is, $C_L = a\alpha_E$, where a is constant and

$$\alpha_E = \Theta_E + \tan^{-1}\frac{U_P}{U_T} \cong \Theta_E + \frac{U_P}{U_T}$$

At the higher airspeeds at which flow separation occurs, however, the section lift coefficient C_L decreases with α_E, while section drag increases sharply. The problem of flow-separation effects had to be dealt with early in the development of the Specific Response Approach. The decision was made to assume that section lift varied linearly with α_E and that an average drag coefficient could be used for all sections; compute performance and flying qualities on the basis of these assumptions; compare the results with data; and, finally, determine the magnitude of the errors and the nature of correction factors that would compensate for them.

Two facts argued for this approach: 1) α_E itself cannot be defined precisely because it is a function of local induced velocity, for which no adequate expression has been developed; and 2) thrust, according to the momentum theory, is a function of mean induced velocity. The premise was that the assumptions of uniform induced flow and linearity of C_L, and the use of an average section drag coefficient, together would produce smaller errors in rotor forces and moments than those inherent in other approaches, which depend heavily on accurate representation of local induced velocity. Furthermore, the simple expressions for forces and moments that would result, with cross-coupling and other effects clearly displayed, would be susceptible to modification by correction factors if they should be needed.

Proceeding as outlined above, SECOR has to date constructed accurate models of the HH-3F, HH-52A, CH-3E, HH-53C, and TH-1L helicopters. In the development of these models it was found

that where the effects of flow separation are perceptible, they can be compensated for by two measures: 1) applying a correction factor to the profile power losses as a function of excess of airspeed over the drag-divergence velocity; and 2) in simulators equipped with a motion system, introducing the vibratory and other effects of stall into that system. The correction for drag divergence is discussed in the derivation of the equation for main rotor torque. The velocity at which stall effects are incipient is determined directly from flight manual stall charts.

Letting $C_L = a\alpha_E$, then, and setting $U_E = U_T$, the equation for elemental thrust can be written:

$$dT = \frac{1}{2} \rho \, ac \, (\theta_E \, U_T^2 + U_T \, U_P) \, dr$$

With the expansion of the terms in parentheses and the substitution of $\beta\Psi = a_o - a_1 \cos\Psi - b_1 \sin\Psi$ and $\dot{\beta}\Psi = \Omega \, (a_1 \sin\Psi - b_1 \sin\Psi)$ we have an expression such that dT (and hence r dT) is integrable along the blade and around the disk. The result of the integration, $\int_e^{BR} r \, dT$ is substituted in the equation for moments about the flapping hinge. The functions of double angles are discarded and the remaining terms are collected to yield the free term, the coefficient of $\sin\Psi$, and the coefficient of $\cos\Psi$. The free term, set to zero, can be solved for the mean flapping angle, or coning angle, a_o. The coefficients of $\sin\Psi$ and $\cos\Psi$, set to zero, can be solved for a_1 and b_1, respectively.

With the integration of the elemental expression dT along the blade and around the disk the average thrust per blade is obtained. The total thrust (less ground effects) is then the product of the number of blades and the average thrust per blade:

$$T = \frac{b}{2\pi} \int_0^{2\pi} \int_e^{BR} \frac{dT}{dr} \, dr \, d\Psi$$

Since $\int_0^{2\pi} \sin\Psi = \int_0^{2\pi} \cos\Psi = \int_0^{2\pi} \sin\Psi \cos\Psi = \int_0^{2\pi} \sin^2\Psi$

$\cos\Psi = \int_0^{2\pi} \sin\Psi \cos^2\Psi = 0$, the final equation for total thrust is relatively simple; most of the terms of the expansion of the elemental expression vanish in integration around the disk.

Ground effects are introduced as a function of slipstream length L_{ss}, which is determined from forward velocity, induced velocity, and the height of the craft above the field.

The final form of the thrust equation is:

$$T = \sigma \left[\Theta_E \left(k_1 \Omega^2 + k_2 V_{xy}^2 \right) + k_3 W' + k_4 \left(p\,U + q_1 V \right) \right] f(L_{ss})$$

The constants depend only on the physical characteristics of the blade. The term $k_4 \, (p\,U + q_1\,V)$ is generally so small that it is eliminated from the thrust equation.

The preceding equations for thrust and flap coefficients were based on a rotor system with an untwisted blade and no cyclic variation in pitch. Where blade has a twist distributed linearly along the blade, the blade element pitch $\Theta_E = \Theta_o + K(r)$, where Θ_o is the blade pitch at the root. This expression for Θ_E can be substituted in the thrust equation before integration. Where twist is linear, it has proved quite accurate to consider Θ_E as the pitch at a distance of 0.75R from the center of rotation; that is, for Θ_E the substitution Θ_{75} is made where $\Theta_{75} = \Theta_o + .75\text{x}$ total twist.

The root blade pitch angle at each azimuth location around the rotor disk depends on the effective control settings developed by the flight control system. The pitch at the root

of the blade varies cyclically according to the expression:

$$\theta = \theta_0 - A_{1s} \cos\psi - B_{1s} \sin\psi$$

Flap coefficients for a rotor with cyclic pitch change are developed in exactly the same way as for a rotor with constant pitch. They are derived with respect to the no-feathering plane of the rotor, however; that is, they are developed with respect to the plane of constant pitch rather than with respect to the plane perpendicular to the shaft. The inflow velocity into the no-feathering plane has components of forward and side velocities approximately equal to $U B_{1s} + V A_{1s}$. To distinguish this inflow velocity from W', the inflow velocity for the rotor with constant pitch, it is represented by:

$$W'' = W - W_{im} - U B_{1s} - V A_{1s}$$

The substitution of W" for W' in the thrust and flap equations yields the thrust, and the coefficients of flapping with respect to the no-feathering plane, of the rotor with cyclic pitch change.

The relationship between the flap angles with respect to the no-feathering plane and the flap angles with respect to a plane perpendicular to the shaft is illustrated in Figure A1-6. Note that:

$$a_{1s} = a_1 - B_{1s}$$

$$b_{1s} = b_1 + A_{1s}$$

The angle B_{1s} is conventionally measured positive counterclockwise from the plane perpendicular to the shaft; the angles a_1 and b_1, positive clockwise from the no-feathering plane, the angles A_{1s}, a_{1s} and b_{1s}, positive clockwise from the plane perpendicular to the shaft.

Rotor torque is computed as $(550/\Omega)\ SHP_R$. In the SRA approach SHP_R is taken as the sum of the individual power-absorbing elements:

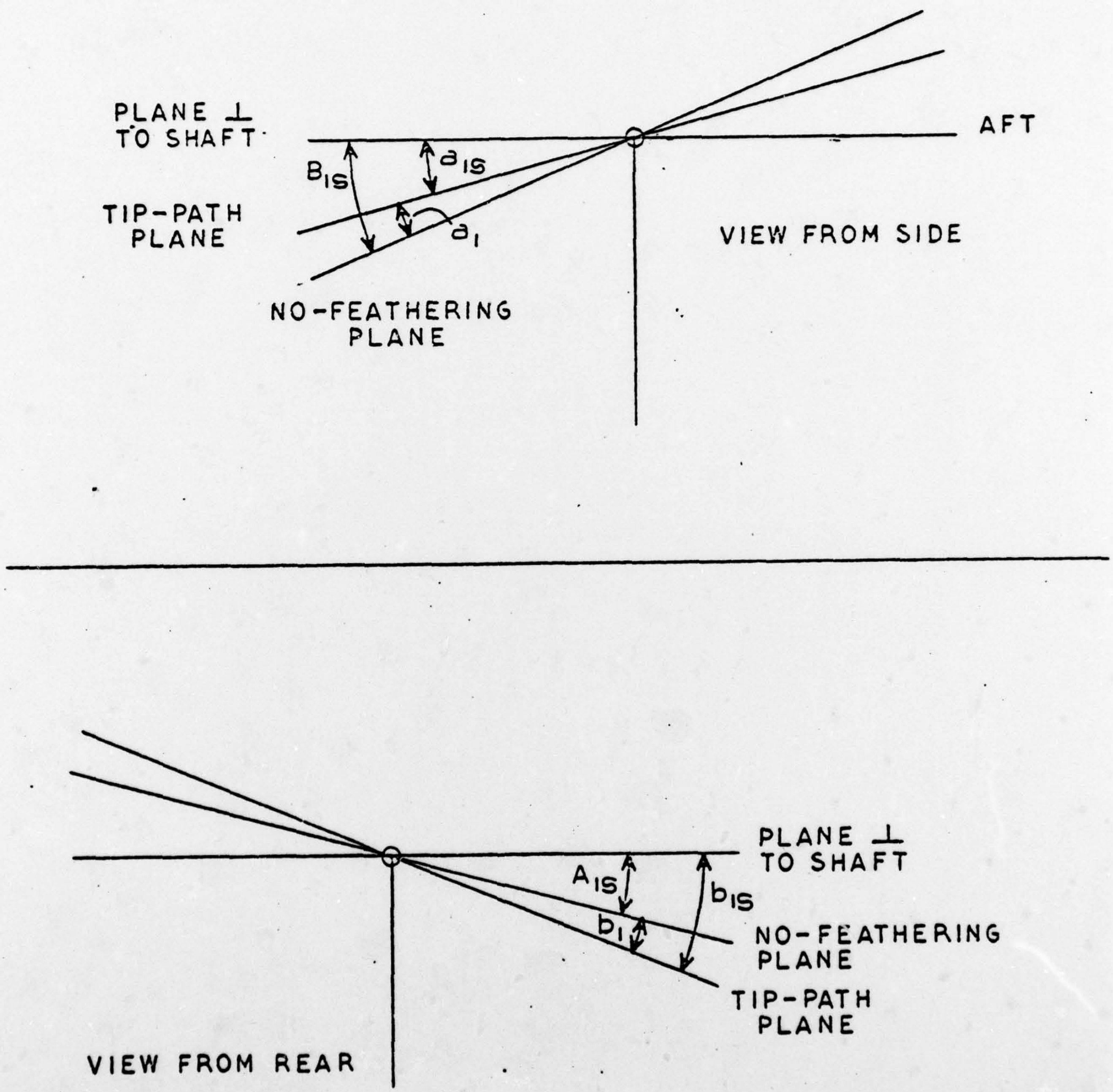


FIG. A1-6 FLAP AND CONTROL ANGLES

$$Q_R = \frac{550}{\Omega} (hp_p + hp_i + hp_o + hp_c + hp_{acc})$$

where:

hp_p = power to overcome parasite drag

hp_i = power to overcome induced drag

hp_o = power to overcome profile drag

hp_c = power to climb

hp_{acc} = power to accelerate

The parasite drag element hp_p is computed by

$$hp_p = \frac{\text{Drag x } V_{xy}}{550} + \frac{1}{2}\rho V_{xy}^3 C_D f$$

In this expression f is the equivalent flat-plate area of the helicopter. Setting $k_1 = \frac{1}{2} \rho_o C_D f$,

$$hp_p = k_1 \sigma V_{xy}^3$$

The power to overcome induced drag is simply

$$hp_i = T W_{im}/550 = k_2 T W_{im}$$

To determine the power to overcome profile drag, the mean profile drag coefficient C_{DAV} is derived as a function of thrust and forward velocity. Then

$$hp_o = \frac{bc \rho C_{DAV} R (\Omega R)^3}{4400} \quad (1 + \frac{4.65 V_{xy}^2}{\Omega^2 R^2})$$

The term $4.65 V_{xy}^2/(\Omega^2 R^2)$ is included to account for radial flow. Simplifying,

$$hp_o = k_3 \sigma C_{DAV} (\Omega^2 + k_4 V_{xy}^2)$$

Power to climb is

$$hp_c = T \dot{h}/550 = k_2 T \dot{h}$$

Power to accelerate is

$$hp_{acc} = m_i \dot{V}_T/550$$

Combining terms,

$$Q_R = \frac{550}{\Omega} \left\{ k_1 \quad V_{xy}^{\ 3} + k_2 \quad \left[T\ (W_{im} + \dot{h}) + k_3 \rho\ C_{DAV} \right.\right.$$

$$\left.\left. (\Omega^2 + k_4\ V_{xy}^{\ 2} + m_i\ \dot{V}_T\ V_T \right] \right\}$$

This equation must be modified to include the effects of drag divergence. The forward velocity at which drag divergence occurs is derived as a function of thrust and pressure altitude. The rotor shaft horsepower requirements are computed with the foregoing equations for a range of forward airspeeds, gross weights, rotor angular velocities, pressure altitudes, and rates of climb, and summed with other system losses. Values of total shaft horsepower required are plotted directly on aircraft performance curves. A correction factor may be added to the expression for profile drag to bring the computer curves into final congruence with the curves of actual performance. The correction factor has the form $1 + k_5\ f(V_{xy} - V_{DD})$ where k_5 is 0 if $V_{xy} < V_{DD}$, and $k_5 = 1$ if $V_{xy} \geq V_{DD}$.

The modified equation for torque is:

$$Q_R = \frac{550}{\Omega} \left\{ k_1 \sigma\ V_{xy}^{\ 3} + k_2 \quad \left[(W_{im} + \dot{h}) + m_i\ \dot{V}_T\ V_T \right] \right.$$

$$\left. + k_3 \sigma\ C_{DAV} \cdot (\Omega^2 + k_4\ V_{xy}^{\ 2}) \quad \left[1 + k_5\ f(V_{xy} - V_{DD}) \right] \right\}$$

The calculation of mean induced velocity is based on the momentum theory. According to this theory the mean induced velocity at hover is

$$W_{im_o} = \frac{T}{2 \pi \rho\ (BR)^2}$$

Variation of W_{im} with airspeed is essentially linear over a portion of the speed regime but nonlinear at transition and high airspeeds. The functional relationship W_{im}/W_{im_o} = $f_1(V_{xy}/W_{im_o})$ is indicated in the lower portion of Figure A1-7.

Also shown on Figure A1-7 is a correction factor accounting for non-uniform flow and slipstream rotation. This factor, too, is a function, f_2, of V_{xy}/W_{im}. In the SRA simulation the two functions are combined to form a single function

$$f(V_{xy}/W_{im_o}) = f_1(V_{xy}/W_{im_o})\ f_2(V_{xy},\ W_{im_o})$$

which is then fitted with straight-line segments for representation in the digital computer. In the real-time simulation program $f(V_{xy}/W_{im_o})$ is generated by linear interpolation. The expression for mean induced velocity, then, is

$$W_{im} = W_{im_o}\ f(V_{xy}/W_{im_o})$$

If the resultant of all aerodynamic forces were perpendicular to the tip-path plane of the rotor, the longitudinal and lateral forces of the rotor would be represented exactly by resolving thrust (T) through the flap angles with respect to the plane perpendicular to the shaft:

$$X_R = -T \sin a_{1s}$$

$$Y_R = T \sin b_{1s}$$

Besides thrust, however, the rotor generates forces parallel to the tip-path plane, and these forces, while generally small compared with the projections of the thrust vector, can be taken into account to refine the equations given above.

The longitudinal and lateral in-plane forces, H_R and S_R respectively, are derived by integrating along the blade and around the disk the elemental expressions

$$dH_R = dD \sin\Psi - dT\, a_o \cos\Psi$$

$$dS_R = -dD \cos\Psi - dT\, a_o \sin\Psi$$

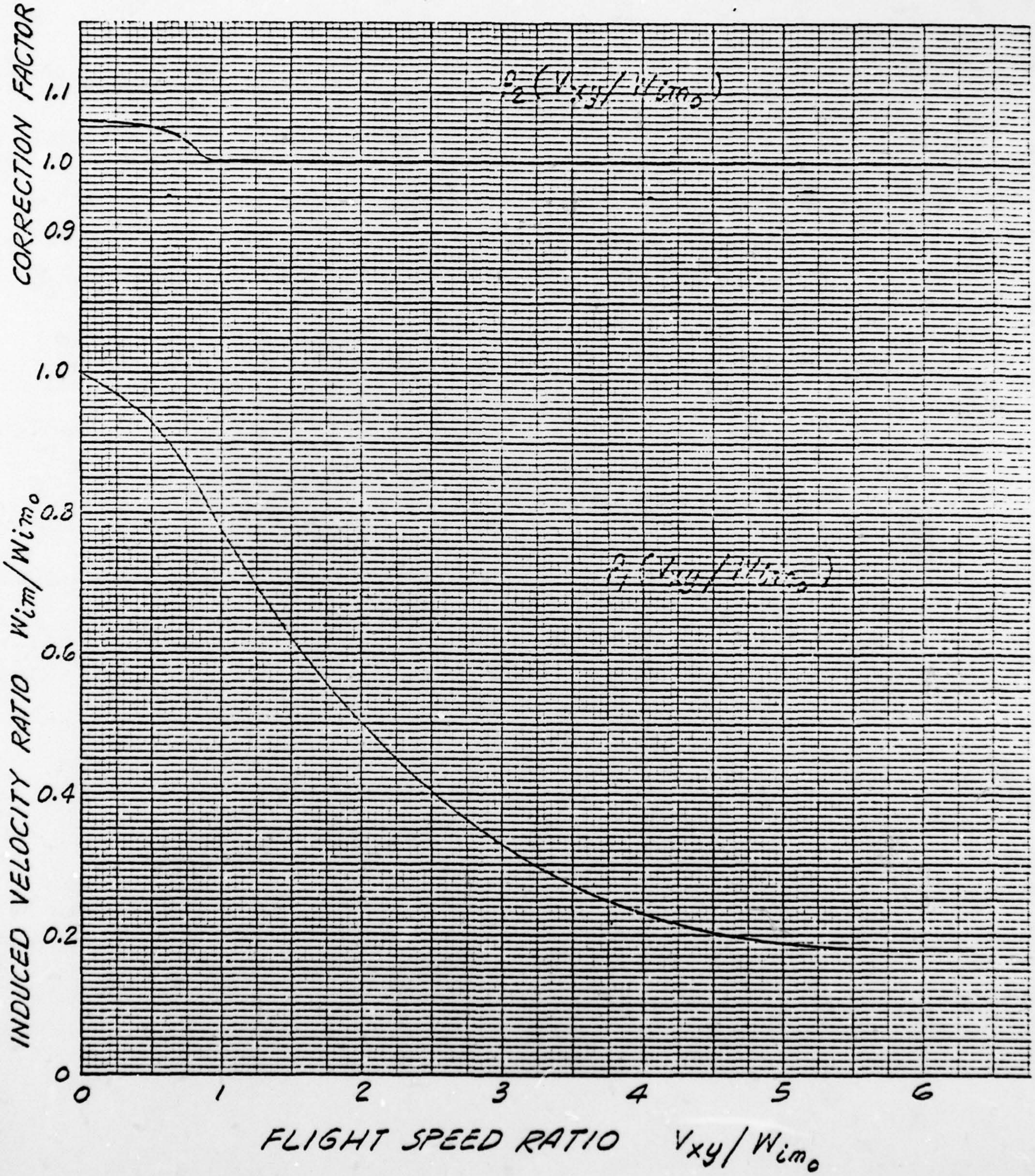


FIG. A.1-7 INDUCED VELOCITY RATIO VS. FLIGHT SPEED RATIO

where

$$dD = -\tfrac{1}{2}\rho c \left[U_T^2{}_{(TP)} C_{DAV} - a \left(\theta_{TP} U_{T(TP)} U_{P(TP)} + U_{P(TP)}^2 \right) \right]$$

and dT is as previously given.

In this equation dD is the elemental drag; θ_{TP} is the effective blade pitch relative to the tip-path plane; U_T and $U_{T(TP)}$ are the velocity components of the wind on the element in the tip-path axes; and C_{DAV} is the average drag.

$$\theta_{TP} = = \theta_E - a_1 \sin\psi + b_1 \cos\psi$$

$$U_{T(TP)} = U_T$$

$$U_{P(TP)} = U_P + U_T (a_1 \sin\psi - b_1 \cos\psi)$$

The average section drag C_{DAV} is computed as a function of thrust and forward velocity as described in the discussion of main-rotor torque. The elements dH_R and dS_R are expanded and integrated along the blade and around the disk to get the average in-plane forces generated by the rotor.

The total rotor force along each body axis is the sum of the projection of thrust and the in-plane force on that axis. With use of the small-angle assumption for a_{1s} and b_{1s}, the expressions for longitudinal and lateral forces become

$$X_R = -T a_{1s} + H_R$$

$$Y_R = T b_{1s} + S_R$$

The positive direction of the Z body axis is downward, so that

$$Z_R = -T$$

The aerodynamic forces just defined, acting through the distances dx, dy, and S_z, create moments about the X, Y and Z axes. In addition, certain moments are imparted to the hub

as the result of forces acting through the arm e, which is the distance of the flapping hinge from the center of rotation. One of these is the inertial force of blade flapping. Projected parallel to the rotor shaft, it creates longitudinal and lateral moments at the hub defined by

$$M_{RH} = b\ M_B r_B\ e\ \frac{1}{2\pi} \int_0^{2\pi} \ddot{\beta}\psi \cos\psi \ \ d\psi$$

$$L_{RH} = b\ M_B r_B\ e\ \frac{1}{2\pi} \int_0^{2\pi} \ddot{\beta}\psi \sin\psi \ \ d\psi$$

With respect to the shaft plane, $\beta\psi$ is expressed by

$$\beta\psi = a_o - a_{1s} \cos\psi - b_{1s} \sin\psi$$

so that

$$\ddot{\beta}\psi = \Omega^2 (a_{1s} \cos\psi + b_{1s} \sin\psi)$$

With integration as indicated

$$M_{RH} = \frac{1}{2} M_B r_B\ e\ b\Omega^2\ a_{1s}$$

and

$$L_{RH} = \frac{1}{2} M_B r_B\ e\ b\Omega^2\ b_{1s}$$

Total moments generated by the main rotor are summarized as follows:

$$L_R = -Y_R\ S_Z + T\ dy + L_{RH}$$

$$M_R = X_R\ S_Z - T\ (dx + S_x) + M_{RH}$$

$$N_R = Q_{MR} + X_R\ dy - Y_R\ (dx + S_x)$$

Figure A1-8 shows the interrelationship of all the rotor equations in block diagram form.

Fuselage/Wing

Approximations to the aerodynamic forces and moments of the fuselage/wing are computed in the conventional manner from

wind-tunnel data. Wind-tunnel data for helicopters, however, is rarely refined enough for simulation accuracy. It seldom includes downwash effects, and it is occasionally taken on a model with structural features differing from those of the production aircraft. In static solutions of the simulation model, errors in wind-tunnel data manifest themselves as errors in aircraft attitude and control deflection. For fidelity of simulation, a good approximation of downwash effects on the fuselage/wing combination is required.

Since wind-tunnel data is generally presented in terms of the stability axis system, fuselage forces and moments will be computed along and about the stability axes and then transformed into the body system.

Ground Handling

Forces and moments imparted to the helicopter on the ground by rolling friction, application of brake pressure, and landing-gear compression occur in the inertial system. Ground-handling forces must be transformed into the body system for summation with other forces and moments as indicated in the summation equations on Figure A1-1.

Other Aerodynamic Effects

Aerodynamic effects of external stores, acting through arms defined by the stores, location with respect to the helicoper CG, will generate increments in the total forces and moments acting on the helicopter. These must be updated as stores are loaded and released.